University Of Alberta

THE QUATERNARY GEOLOGY OF SOUTHEASTERN VANCOUVER ISLAND, BRITISH COLUMBIA

BY

Heather Elizabeth Blyth

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

DEPARTMENT OF GEOLOGY

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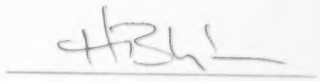
(Signed) 

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Dedicated

to

Mrs. Joan Blyth and Mrs. Beryl Vosper

ABSTRACT

This study maps and reevaluates the Quaternary sediments of southeastern Vancouver Island, an area partially unmapped since 1913. Six 1:50,000 surficial geology maps of southeastern Vancouver Island and the Gulf Islands were published through British Columbia's Ministry of Energy, Mines and Petroleum Resources. This surficial geologic information combined with three new ^{14}C dates, data from twelve key sections, and a review of previous research, are presented and used to develop a new composite stratigraphy for southeastern Vancouver Island and to interpret the Quaternary history and regional aggregate potential of the area. The proposed new composite stratigraphy identifies ten distinct stratigraphic units representing three glacial and three non-glacial periods between the Pre-Sangamon and the Holocene and potential aggregate sources are identified in the Cowichan Valley, the upper Goldstream Valley and at the Muir/Kirby Creek delta.

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Contrary to some people's better judgment, I moved away from the University (four times); I socialized...just a little; I got a job; and, as I am told, I took a little longer than most finishing my degree. Well, I have this to say about that. If you could meet, and work with, people as good as those I have met during my time at the University of Alberta you'd take a few years too.

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INTRODUCTION

Southeastern Vancouver Island (fig. 1) is a key area for deriving a Quaternary geologic history for the Pacific Northwest (western British Columbia and Washington State). It is close to the alpine glaciers of Vancouver Island and the Coast mountains, the major sources of Cordilleran ice. The island's eastern coast exhibits thick sequences of Quaternary deposits and long records of Quaternary history. The location of the study area at the confluence of the Georgia and Juan de Fuca Straits allows insight into the ice flow of the Puget and Juan de Fuca ice lobes of the last glacial period.

In addition to its scientific importance to Quaternary geology, southeastern Vancouver Island was chosen for study due to economic and practical purposes. The region provides aggregate resources for much of southwestern British Columbia. Urban expansion and rezoning are rapidly depleting known aggregate stocks, therefore, knowledge of their distribution will contribute to identifying, and hopefully, preserving future reserves. In addition, growing evidence suggests that southwestern British Columbia lies directly above a seismically active subduction zone (Clague and Bobrowsky, 1994), capable of producing earthquakes of a magnitude of 7.0 or greater (Rogers, 1988; Atwater, 1992). Given this potential seismic hazard, an understanding of the distribution of failure prone sediments should be useful to urban and hazard planners.

The primary study area for this thesis is southeastern Vancouver Island. The surficial maps produced, however, cover a region that extends south of latitude 49°00' North, to the Juan de Fuca Strait, and east from longitude 124°00' West to the east coast of Saturna Island, which includes the southern-most Gulf Islands (fig. 1). The area of study was chosen to update surficial geologic information in an area partially unmapped since 1913.

Objectives

There were three major objectives to this research. Firstly, six 1:50,000 scale surficial geology maps of southeastern Vancouver Island and the Gulf Islands were produced, with particular emphasis placed on the Saanich Peninsula, the region not mapped since 1913. Secondly the stratigraphy was documented and evaluated based on the physical, textural, and lithologic properties of each unit. The various stratigraphic units were then correlated to establish an up-to-date Quaternary geologic history, strictly for southeastern

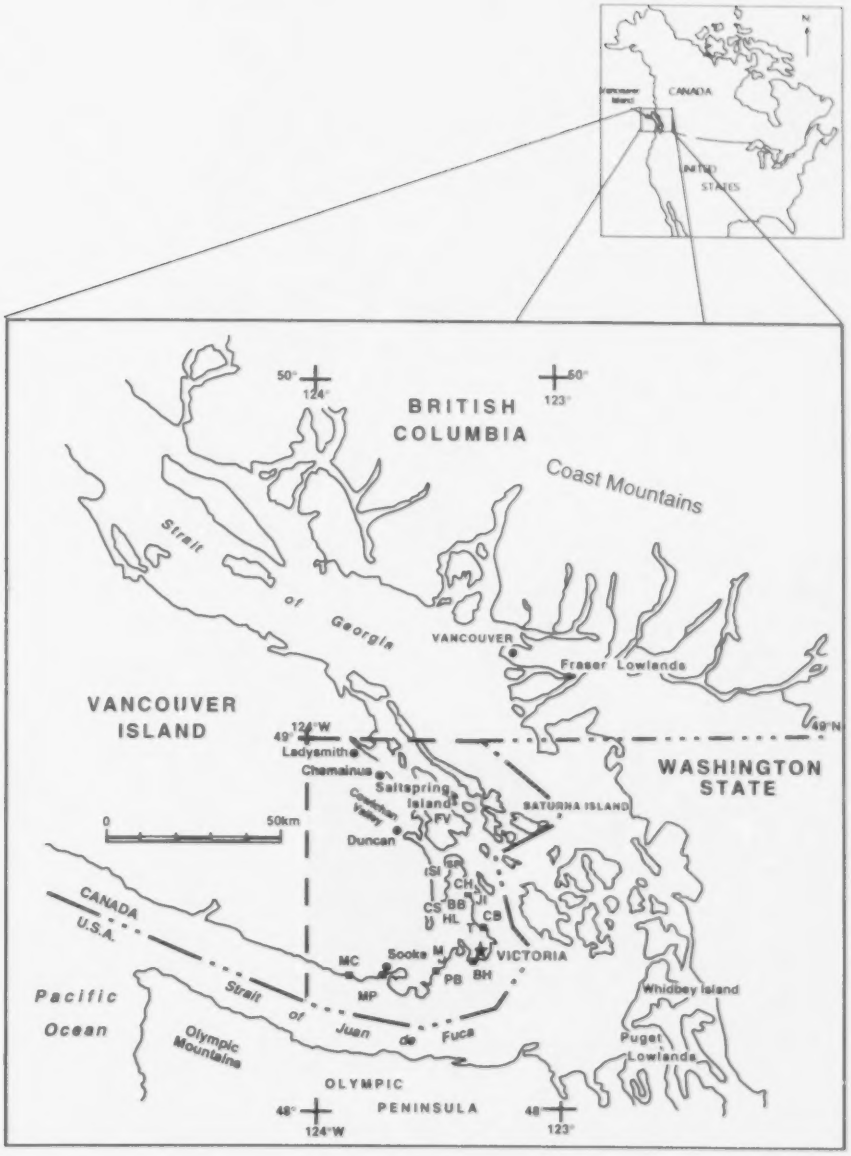


Figure 1: The study location on southeastern Vancouver Island covers an area from 49°00'N to the Strait of Juan de Fuca and from 124° 00' W to as far east as Saturna Island.

Sections and locations: **BH**, Beacon Hill; **BB**, Butler Brothers; **CB**, Cordova Bay; **CH**, Cowichan Head; **CS**, Central Saanich; **FV**, Fulford Valley; **JI**, James Island; **M**, Metchosin; **MC**, Muir Creek; **MP**, Muir Point; **PB**, Parry Bay; **T**, Trio; **SI**, Saanich Inlet and **SP** the Saanich Peninsula.

Vancouver Island. Finally, surface and sub-surface sediments were evaluated to provide information on potential aggregate resources and hazards.

Previous Work

Quaternary Geologic History of Southern Vancouver Island, the Puget and Fraser Lowlands

Quaternary studies of southeastern Vancouver Island began with the work of H. Bauermann (1859) who first noted glacially polished bedrock around the Victoria area. More detailed Quaternary research followed with G.M. Dawson's geologic work of 1881 and 1887 in which he distinguished: 1) two distinct tills, deposited during separate cold periods; and 2) a stratified sand and silt unit deposited during an intervening climatic warming. Dawson (1887) interpreted these units as representing a south-southwestward flowing ice sheet, 600 to 3000 feet (183 to 914 meters) thick, which moved towards the Puget Lowlands and westward through the Strait of Juan de Fuca and over southern Vancouver Island during the last glaciation (fig. 1).

Clapp (1912, 1913, and 1917), later identified a similar stratigraphy to that of Dawson (1887) on southeastern Vancouver Island. He adopted the terminology of Willis (1898), from the Puget Lowlands, to describe deposits from two glaciations with non-glacial sediments 'sandwiched' between them. Clapp (1913) termed the glacial detritus of the older glaciation 'Admiralty till'; the younger non-glacial deposit as 'Puyallup non-glacial sediments' and the glacial detritus of the younger glaciation as 'Vashon drift'. The Puyallup non-glacial sediments were subdivided into the 'Maywood clays' and 'Cordova sands and gravels' (Clapp, 1913). Sand and gravel deposited during the recession of the Vashon glaciation was termed 'Colwood sands and gravels'. The present beach, valley and swamp alluvium deposited since post-glacial uplift of 250 feet (76.2 meters), was also noted (Clapp, 1913). Halstead (1966) identified three tills exposed in cliff sections at Saanich, Victoria and Sooke on southern Vancouver Island. He inferred multiple glaciations and ice flow direction, from at least the last glaciation, southward through the Strait of Georgia (Halstead, 1966).

Since the 1960s, more than fifty studies, carried out within the Pacific Northwest, have contributed to the understanding of the Quaternary geologic history of southeastern Vancouver Island. A summary of previous research and nomenclature is presented in figure 2.

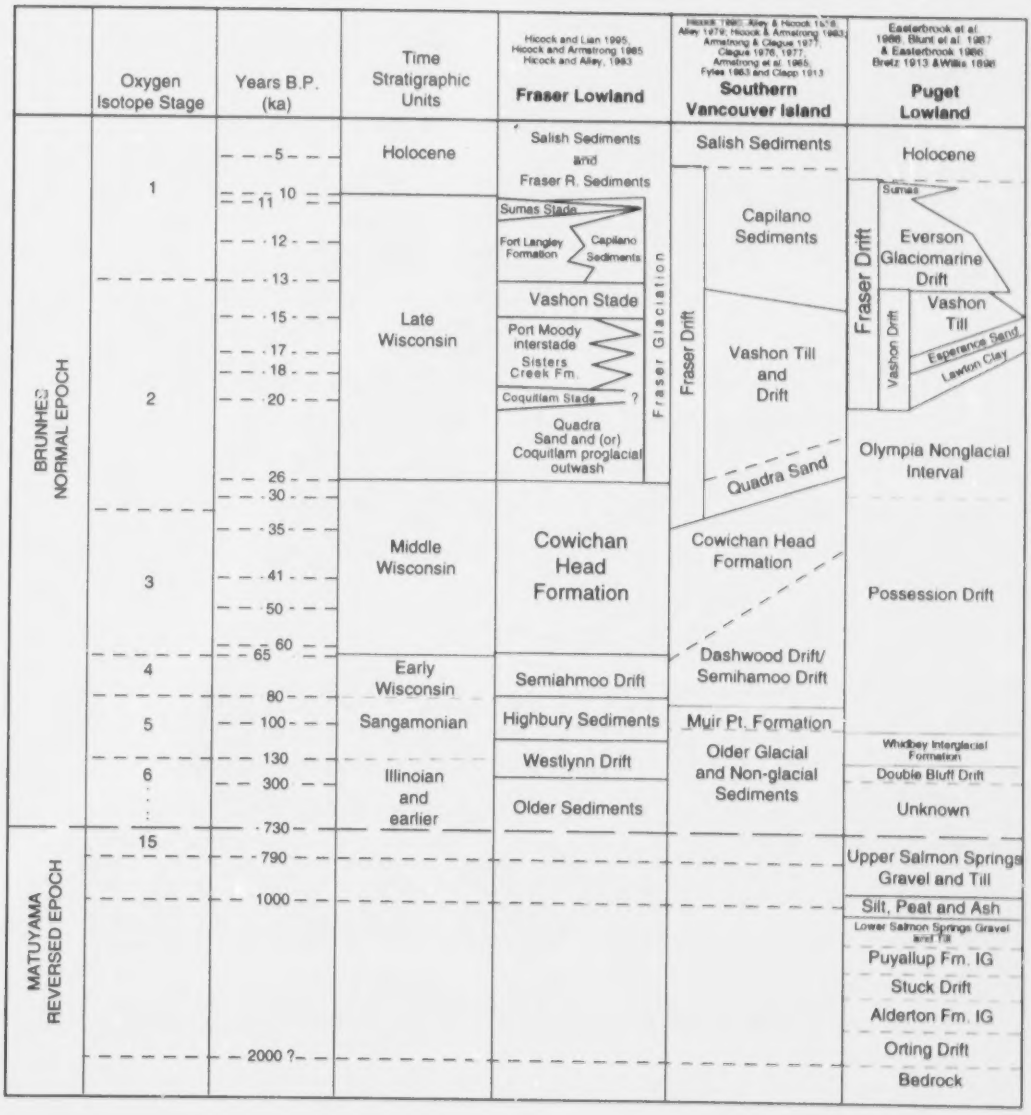


Figure 2: Previous work on the stratigraphy of southern Vancouver Island, and the Puget and Fraser Lowlands

Pre- Sangamon:

Pre-Sangamon deposits of southeastern Vancouver Island are represented by one glacial unit consisting of till. Armstrong (1975), working near Vancouver, identified a glacial deposit which he termed Westlynn drift, beneath palynologically-identified Sangamon sediments. Similar work by Hicock (1980), identified a comparable till and non-glacial sediments beneath Sangamon deposits on southeastern Vancouver Island. These sediments have not been dated and will be herein referred to as older glacial (or non-glacial) sediments.

Sangamon:

The Sangamon is represented on southeastern Vancouver Island by a non-glacial unit of organic-rich silt, sand and gravel. Fyles (1963) identified a non-glacial unit of sand, silt and clay beneath the Early Wisconsinan till (Admiralty till) at Mapleguard Point, on central Vancouver Island. He termed these deposits Mapleguard sediments. The term Mapleguard sediments was later replaced by Muir Point Formation to describe the Sangamon, non-glacial sediments on southeastern Vancouver Island (Hicock, 1980; Hicock and Armstrong, 1983). Halstead (1966) found similar, non-glacial, pre-Wisconsinan gravels exposed at the base of the Cowichan River valley but did not formally name them. Armstrong (1975) revised the nomenclature for the Sangamon non-glacial period of the Fraser Valley by identifying Highbury Sediments which he considered Sangamon in age. Hicock and Armstrong (1983) established type sections for the Highbury Sediments of the Fraser lowland and the Muir Point Formation of southern Vancouver Island. Based on stratigraphic position and lithologic similarity, the Highbury Sediments may be correlative with the Muir Point Formation (Hicock and Armstrong, 1983) (fig. 2). Palynological evidence from both sections suggested deposition in a climate at least as warm as present, i.e. Interglacial (Hicock and Armstrong, 1983).

Alley and Hicock (1986) expanded on the work of Hicock and Armstrong (1983) using palynological evidence to show that Muir Point sediments were correlative with the Whidbey Interglacial Formation (Easterbrook *et al.*, 1967; Easterbrook, 1969) in the Puget lowlands (fig. 2). Pollen assemblages from Muir Point were interpreted as "the oldest Pleistocene microfloras yet described from British Columbia" (Alley and Hicock, 1986, p. 381).

Hicock (1990) demonstrated that the Muir Point Formation has a normal paleomagnetic signature implying an age younger than the Brunes-Matyama reversal of

730,000 y BP. Using palynological evidence, he placed the Muir Point Formation within the Interglacial and climatic maximum of the Late Pleistocene. Hicock (1990) confirmed the correlation between the Muir Point Formation of southern Vancouver Island and the Whidbey Formation of northwestern Washington State (fig. 2). He suggested a correlation existed between the Muir Point Formation and the Highbury Formation of the Fraser lowland in British Columbia (fig. 2); an idea previously suggested by Hicock and Armstrong (1983).

Thermal luminescence was used to date the Whidbey Formation of northwestern Washington State (Berger and Easterbrook, 1993). Ages ranged from 102,000 +/- 38,000 y BP to 151,000 +/- 43,000 y BP (Berger and Easterbrook, 1993). Lian *et al.*, (1995) tested the effectiveness of optical luminescence (OL) dating to determine the age of the Muir Point and Whidbey Formations (fig. 2). In support of Berger and Easterbrook (1993) he found that his results indicated that both formations were deposited between 107,000 and 119,000 y BP. Terminology for sediments deposited within this time range, or correlative with Sangamon Interglacial deposits on southeastern Vancouver Island, will be referred to as the Muir Point Formation after Hicock (1980) and Hicock and Armstrong (1983).

Early Wisco .sinan:

The Early Wisconsinan glaciation on Vancouver Island, known as the Semiahmoo Glaciation, is evidenced by Dashwood drift (Fyles, 1963). Dashwood drift, formerly known as Admiralty till (Clapp, 1913), is composed of fossiliferous glaciomarine till and glaciofluvial deposits. Halstead (1966, p. 2) described a silty to gravely, "concrete-like" till in the Cowichan Valley which he correlated with the Dashwood drift of Fyles (1963). Armstrong (1975) revised the Fraser Lowland stratigraphy to include an Early Wisconsinan glacial deposit which he termed Semiahmoo drift.

A correlation between the Semiahmoo drift of the Fraser Lowland and the Dashwood drift of Vancouver Island was first proposed by Hicock and Armstrong (1983) (fig. 2). Hicock and Rutter (1986) used aminostratigraphy to show a probable correlation between the Dashwood drift of Vancouver Island, the Semiahmoo drift of the Fraser Lowlands and the Possession glaciomarine sediments of the Puget Lowlands (Willis, 1898). Dashwood drift is used here to refer to glacial sediments of the Semiahmoo Glaciation after the work of Fyles (1963) on southern Vancouver Island (fig. 2).

Middle Wisconsinan:

Deposits of the Middle Wisconsinan are represented on southeastern Vancouver Island by non-glacial, oxidized, organic rich, silt, sand and gravel located above the Early Wisconsinan Dashwood drift (Fyles, 1963). Fyles (1963) originally identified a non-glacial unit of marine clay, stony clay, plant-bearing silt, sand and gravel overlain by a thick upper unit of white sand and plant-bearing silt, as the Quadra sediments, after a similar depositional sequence found near Vancouver (Johnston, 1923; Armstrong and Brown, 1953). However, Armstrong *et al.* (1965) detailed the stratigraphy of the Mid- to Late Wisconsinan, specifically in the Fraser Lowlands, by dividing the Quadra sediments, defined by Fyles (1963), into two major units. The first, a plant-bearing silt, sand and gravel was termed Mid-Wisconsinan, Olympia Interglacial deposits, which were interpreted to have been deposited between 36,000 y BP and the onset of the last glaciation, the Fraser glaciation (Armstrong *et al.*, 1965). The second unit, a thick upper deposit of white sand, was termed Quadra sands (Armstrong *et al.*, 1965) and dated as Late Wisconsinan (<25,000 y BP).

The Mid-Wisconsinan, Olympia non-glacial deposits are best represented at Cowichan Head on southeastern Vancouver Island by the Cowichan Head Formation (Clague, 1976; 1977). Numerous radiocarbon dates from eastern Vancouver Island suggest that this non-glacial period existed between 58,000 y BP to approximately 29,000 y BP (Fulton, 1971; Fulton *et al.*, 1976; Clague, 1976, 1977; Armstrong and Clague, 1977). Clague (1978) used terrestrial, lithologic and biostratigraphic information and data from deep sea cores to show that although the Mid- Wisconsinan climate fluctuated sharply, it was generally cooler than at present and represented a non-glacial climate. According to Alley (1979), the mid-Wisconsinan was represented by full interglacial conditions between 51,000 y BP and 29,000 y BP. Gascoyne *et al.*, (1980; 1981), studying speleothems on central Vancouver Island, interpreted continuous non-glacial conditions between 64,000 y BP and approximately 28,000 y BP. They identified a steadily declining temperature from 4° to 0° Celsius over this time period. Recent research has optically dated the Cowichan Head Formation between ~68,000 and ~25,000 y BP (Hicock, 1995 pers. comm.; Lian *et al.*, 1995). The terminology of Clague (1976, 1977) and the climatic connotations of Gascoyne *et al.*, (1980, 1981) are used in this study to identify sediments of the Olympia non-glacial period as Cowichan Head Formation deposits.

Late Wisconsinan:

On southeastern Vancouver Island and throughout the Georgia Depression the beginning of Late Wisconsinan climatic deterioration is represented by Quadra Sand (Clague, 1976, 1977; Armstrong and Clague, 1977). Clague (1976, 1977) identified the Quadra Sand as a pro-glacial sequence of mostly sand and lesser gravel, deposited during the advance of the Late Wisconsinan, Fraser glaciation (from ~28,800 in alpine areas to 21,000 y BP at lower elevations). Previous studies grouped the Quadra sands with Mid-Wisconsinan non-glacial sediments (Johnston, 1923; Armstrong and Brown, 1953; Fyles, 1963), however, palynological evidence suggest that they were deposited in a climate which "deteriorated until tundra like conditions prevailed" (Alley, 1979, p. 213).

Armstrong *et al.* (1965) named the Late Wisconsinan glaciation, in the Pacific Northwest, the Fraser glaciation. Till and drift from this glaciation was termed Vashon drift (Willis, 1898). The major advance of the Fraser glaciation did not begin until 18,000 y BP (Clague *et al.*, 1980) and it did not reach its maximum, the Vashon Stade (Willis, 1898), until 14,500y B.P. (Clague *et al.*, 1980; Armstrong, 1981; Hicock *et al.*, 1982; Easterbrook, 1986; Easterbrook, 1992; Hicock and Lian, 1995). This inferred that the Vashon Stade occurred more than three thousand years after the global and Laurentide glacial maximums of 18,000 y BP (CLIMAP, 1976; COHMAP, 1988; Hicock and Lian, 1995;).

Since the Vashon drift lies unconformably on Quadra sediments, Howes and Nasmith (1983) used dates from the upper Quadra Sands to show that Fraser ice had not reached southeastern Vancouver Island until some time after 17,000 y BP. Their work confirmed the earlier work of Clague (1976) which suggested that several thousands of years separated the alpine from ice sheet phases of the Fraser glaciation. More recent work by Hicock and Armstrong (1981) suggests that the Fraser glaciation was preceded by ice advancing out of the alpine areas around 20,000 y BP during what they termed the Coquitlam stade. Ice from the Coquitlam stade is interpreted to have receded by about 19,000 y BP in what Hicock and Lian (1995) identify as the Port Moody Interstade. This interstade lasted from approximately 19,000 y BP (Hicock and Lian, 1995) to about 15,500 y BP (Hicock and Armstrong, 1985), the onset of the Vashon Stade (fig. 2).

Halstead (1966) studied the surficial deposits, erratics, striae, and stoss and lee features associated with the Fraser Glaciation, in the Duncan and Shawnigan map areas of southeastern Vancouver Island. He concluded that ice from the Fraser glaciation was probably a minimum of 5000 feet (1524 meters) thick, and noted that it moved in a south to

southwest direction through the Strait of Georgia and over ice from the Cowichan Valley (fig. 1). Halstead (1966) interpreted the surface stony till and glaciomarine stony clay as Vashon drift. Alley and Chatwin (1979) determined that during the Vashon Stade, southern Vancouver Island was completely covered by ice. The ice split into two lobes, one of which flowed southward into the Puget Lowland (the Puget Lobe) and the other in a south-southwesterly direction through the Juan de Fuca Strait (the Juan de Fuca Lobe) to its terminus at the edge of the continental shelf (Alley and Chatwin, 1979).

Armstrong *et al.* (1965) and Mathews *et al.* (1970) suggested that Vashon ice melted and marine waters transgressed into the depressed, coastal lowlands of southwestern British Columbia between 13,000 and 11,000 y BP. Synchronous and rapid isostatic emergence occurred at this time and ceased around 8000 y BP (Mathews *et al.*, 1970; Fulton, 1971). Armstrong *et al.* (1965) identified the post Vashon period of deglaciation and marine incursion, as the Everson Interstade. Sediments deposited during the Everson Interstade were termed Capilano Sediments (Armstrong and Brown, 1953; Armstrong, 1956). These sediments included glaciomarine, glaciofluvial and marine materials deposited between ~13,000 y BP and 11,000 y BP (Armstrong, 1956, 1981). Armstrong (1981) subdivided the Capilano sediments overlain by Sumas Drift (from the Sumas Stade 11,400 y BP to 11,000 y BP; Armstrong, 1956) and termed them Fort Langley Formation, deposited between ~13,000 y BP and 11,400 y BP (Armstrong, 1981) (fig. 2). Where applicable the aforementioned terms have been adopted by the author.

On southern Vancouver Island, Vashon ice retreated and marine incursion occurred around 12,500 to 12,750 y BP (Halstead, 1966; Mathews *et al.*, 1970; Fulton, 1971). Fyles (1963) adopted the terminology of Armstrong (1956) to identify the thick glaciomarine and marine coastal deposits as Capilano Sediments. Armstrong (1981) suggested that the Capilano Sediments of Vancouver Island were probably correlative with those of the Fraser Lowlands, a point later confirmed by Hicock and Rutter (1986).

The Sumas stade (Armstrong *et al.*, 1965; Armstrong, 1965; Armstrong, 1981), is represented by a till, deposited around 11,400 y BP, which overlies glaciomarine deposits of the Fort Langley Formation (Armstrong, 1981). It may represent a readvance of Cordilleran piedmont ice (Armstrong *et al.*, 1965; Armstrong, 1981), or the grounding of a previously floating ice shelf (Easterbrook 1963).

Holocene:

On Vancouver Island, the post-glacial sand and gravel terraces, modern shoreline, and bog deposits of Holocene age are termed Salish Sediments (Fyles, 1963), after the work of Armstrong and Brown (1953). These include aboriginal midden deposits found around three meters above high tide and fluvial deposits found within 4.6 meters of high water.

Late Quaternary Sea Level:

Changes in sea level are responsible for the preservation and exposure of some of oldest and most extensive Quaternary sections in western Canada. Its fluctuations have created the deltas and raised beaches which presently form the majority of the regions' aggregate resources. The sea level history for southeastern Vancouver Island is a result of a complex interrelationship between isostatic adjustment, glacial down wasting, sediment loading, eustatic flux and tectonic movement. Post-glacial sea level curves have been compiled in the eastern Vancouver Island (Mathews *et al.*, 1970) and Victoria areas (Linden and Schurer, 1988) and adjusted to global curves (Blanchon and Shaw, 1995) to show eustatic versus isostatic variations (fig. 3).

Regional sea level curves indicate an upper marine limit ranging from 175 meters above modern sea level in the Vancouver area to only 75 meters near Victoria (Clague, 1975). The post-glacial sea level high was immediately followed by a rapid coastal emergence whereby sea level on southeastern Vancouver Island dropped to near present level by 11,700 +/- 170 years B.P. (Linden and Schurer, 1988) (fig. 3). It then rose to a second peak at approximately 11,500 y BP (Mathews *et al.*, 1970; Clague *et al.*, 1982) and between 11,500 y BP and 5000 y BP had risen only a few meters, to near its present level (Foster, 1972; Clague, 1975; Clague, 1981; Clague *et al.*, 1982; Booth, 1987). With the exception of minor tectonically related transgressions (Clague and Bobrowsky, 1990), sea level has changed no more than one meter from its present position in the past 2000 years (Clague, 1989; Clague and Bobrowsky, 1990).

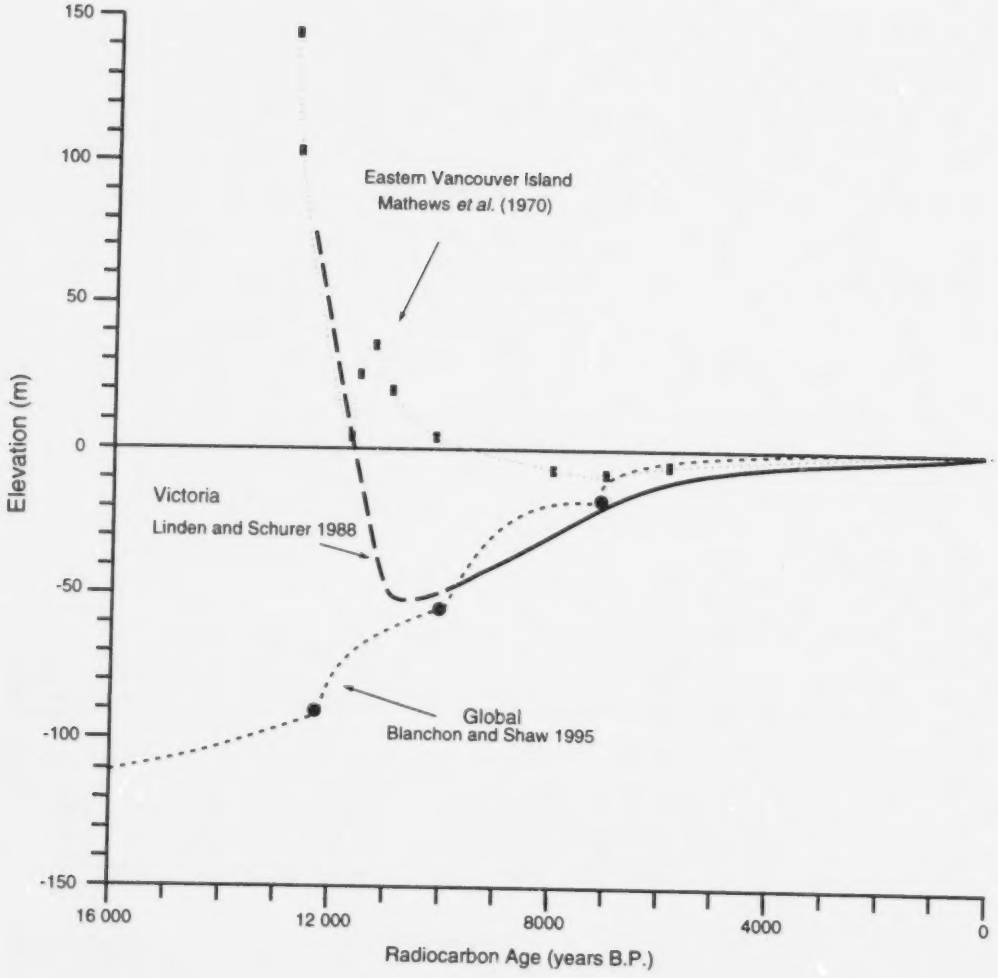


Figure 3: Southeastern Vancouver Island and Global Sea Level Curves.

Physiographic and Geologic Setting

Southeastern Vancouver Island is part of a large, northwesterly trending, physiographic zone known as the "Coast Mountains and Islands Region" (Valentine *et al.*, 1978). It is composed of the Vancouver Island Mountains and the Georgia Depression, which is mostly occupied by the waters of the Georgia Strait (fig. 4). The Vancouver Island Mountains dominate the western portion of the study area while the Georgia Depression forms a ridged lowland to the east.

The rugged, north-northwesterly trending Vancouver Island Mountains are composed of resistant meta-sedimentary, meta-volcanic and intrusive bedrock lithologies (Muller, 1982; Massey, 1994). These lithologies are found predominantly in the central and western portions of Vancouver Island and form the topographic highs, 600 to 1200 meters above sea level, in the western portion of the study area.

The Georgia Depression is a northwest trending, partly submerged coastal trough situated between the Coast Mountains of the British Columbia mainland and the Vancouver Island Mountains to the west-southwest (fig. 4). Bedrock within the depression consists of shale, mudstone, sandstone and conglomerate. The Georgia Depression extends from the British Columbia coast to the Puget Lowlands of Washington State and forms a broad physiographic region whose land masses average no more than 200-300 meters above sea level. Differential erosion of shales and mudstones versus resistant sandstone and conglomerates, has created a region of bedrock-controlled, northwest to southeast striking ridges, islands and valleys.

Although the landscape is bedrock controlled, glacial processes have played a major role in the physiographic development of southeastern Vancouver Island. Thick sequences of Quaternary sediments have generally subdued the landscape, particularly along the eastern coast of Vancouver Island between Ladysmith and Victoria (fig. 1). Glacial erosion has produced large roches moutonnées, drumlins (fig. 5), fjords and U-shaped valleys. Exposed, well striated and fluted bedrock (fig. 6), is found throughout southeastern Vancouver Island and provides a useful indication of glacial ice flow directions.

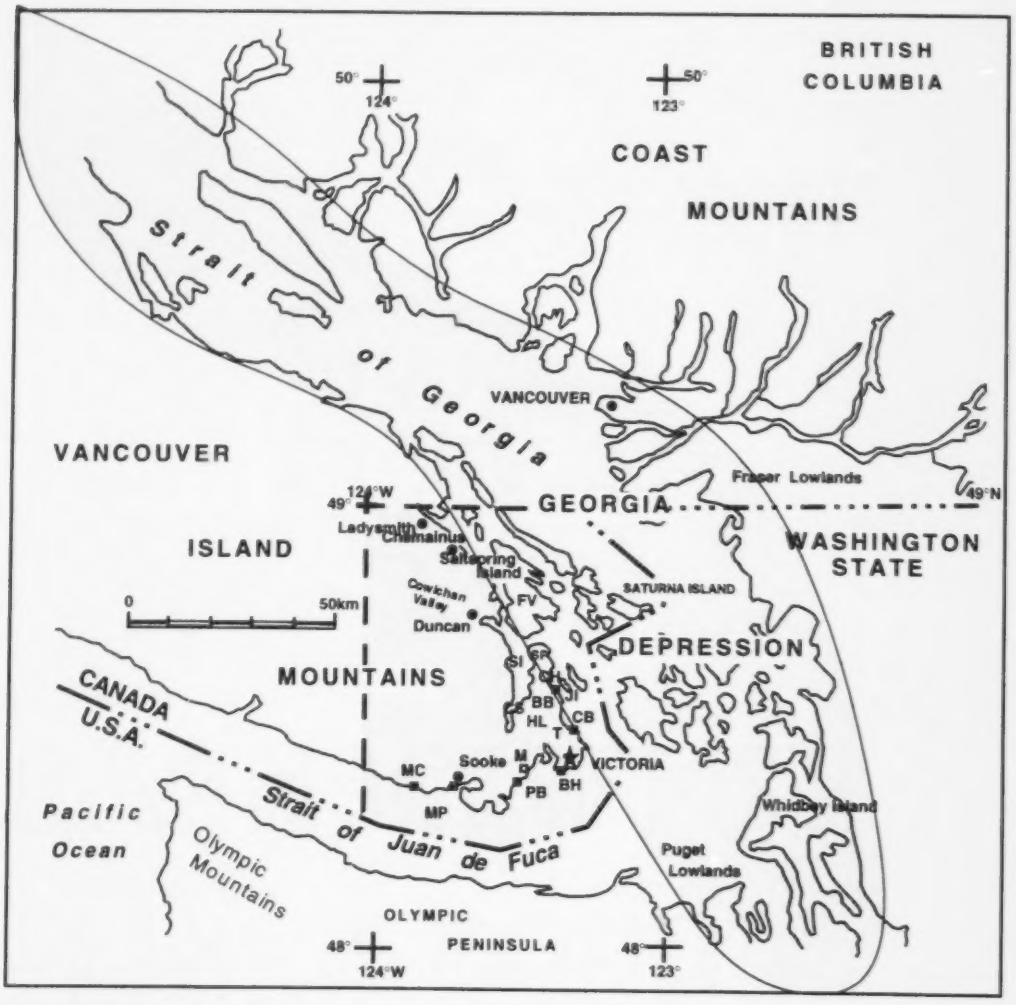


Figure 4: Physiography - The Coast Mountain and Island Region - Georgia Depression

Sections and locations: **BH**, Beacon Hill; **BB**, Butler Brothers; **CB**, Cordova Bay; **CH**, Cowichan Head; **CS**, Central Saanich; **FV**, Fulford Valley; **JI**, James Island; **M**, Metchosin; **MC**, Muir Creek; **MP**, Muir Point; **PB**, Parry Bay; **T**, Trio; **SI**, Saanich Inlet and **SP** the Saanich Peninsula.

Figure 5: James Island Drumlin Looking Northeastward

Figure 6: Fluted and Striated Bedrock at the Metchosin Gravel Pit Facing 280° Northwest

Bedrock Geology

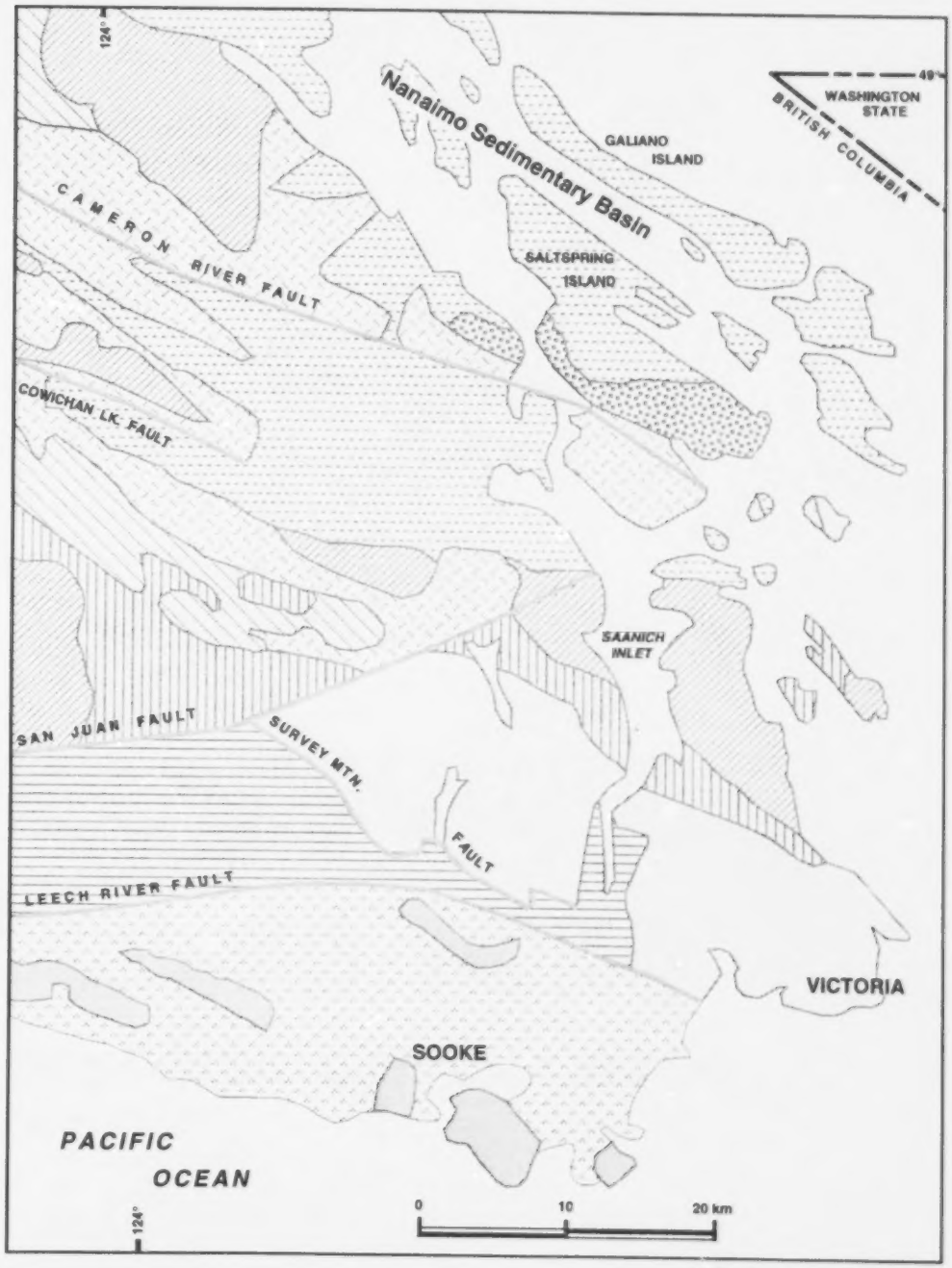
Important in identifying the provenance of tills on southeastern Vancouver Island, is the bedrock geology of the island and surrounding area. Southeastern Vancouver Island is located within the Canadian Cordillera, an accretionary complex of allochthonous and autochthonous bedrock terranes that extend from Alaska to California (Jones *et al.*, 1977; Monger and Price, 1979; Monger *et al.*, 1982; Windley, 1984; Chamberlain and Lambert, 1985; Lambert and Chamberlain, 1988). Terrane accretion formed the northwest trending physiographic patterns of Vancouver Island and provided depressions that controlled the ice flow paths of successive glaciations. Erratics derived from the terranes allow ice provenance to be determined.

During the accretion of the major Cordilleran terranes many smaller, allochthonous terranes were incorporated in the Cordilleran complex (Coney *et al.*, 1980). Among those allochthonous terranes, accreted at a more southerly latitude than present, was Wrangellia, the dominant terrane forming Vancouver Island (Coney *et al.*, 1980; Yorath, 1988). Wrangellia is an Upper Paleozoic, sub-marine to sub-aerial island arc complex consisting of volcaniclastic flows and breccias overlain by limestones, clastics, cherts and Mesozoic pillowed, sub-marine and sheeted, sub-aerial basalt (Yorath, 1988). It slowly drifted northeastward to eventually collide with the North American continent and form the base of Vancouver Island some 40-90 million years ago (Coney *et al.*, 1980). During the Cretaceous, Wrangellia was tectonically compressed and uplifted to form the Vancouver Island mountains we now see extending the length of the island.

Associated with this Cretaceous orogenic period was a period of increased erosion and sedimentary deposition on the east side of the Island in what is called the Nanaimo sedimentary basin (located within the Georgia Depression physiographic region). These deposits formed the Nanaimo Group sedimentary complex consisting of marine and non-marine sandstones, siltstones and conglomerates. Around 30 million years ago, the Nanaimo sediments were compressed and uplifted by the collision of two more allochthonous terranes on the west coast of Vancouver Island. These terranes are known as the Pacific Rim and Crescent Terranes (Yorath, 1988). Today the slightly deformed Nanaimo sediments are found throughout the Georgia Depression and lowland areas of Vancouver Island (fig. 7).

The Pacific Rim Terrane (Karmutsen Formation, fig. 7) is composed of Triassic to Cretaceous volcanic breccia, flow basalt, minor pillowed flows, chert, grey limestone lenses and minor dioritic intrusions (Massey, 1994). The Crescent Terrane, however, consists of

Figure 7: Bedrock Geology of Southeastern Vancouver Island



(After Massey 1994 and Muller 1980)

- Paleocene to Eocene Metchosin Igneous Complex (Sooke Gabbros)
- Paleocene to Eocene Igneous Complex (submarine basalt and limestone)
- Late Cretaceous (Nanaimo Group) Sediments
- Jurassic to Cretaceous Leech River Complex (Meta- sediments and volcanics)
- Late Jurassic (Bonanza Group) Volcanics
- Early to Middle Jurassic Plutonic Suite (Dioritic,Island Intrusions)
- Mid-Upper Triassic (Karmutsen) Volcanics with limestone
- Late Devonian Saltspring Intrusions Suite - Granodiorite, feldspar porhpyry
- Middle to Upper Devonian (Sicker Group) Volcanics and Sediments
- Paleozoic to Jurassic West Coast Crystalline Complex (Wark and Colquitz gneiss) Metamorphics

Paleocene to Eocene deep marine rocks such as layered gabbros, pillowed basalts, sheeted dikes, breccias, tuffs and rare limestones (locally termed the Metchosin Igneous Complex) (Yorath, 1988; Massey, 1994; fig. 7).

Climate, Soils and Vegetation

Climate, soils and vegetation are described here to provide a reference for comparison of Quaternary palynological and macrofossil data presented within this thesis. Southeastern Vancouver Island is identified as having a "Transitional Cool Mediterranean Climate" (van Vliet *et al.*, 1991, p.8) characterized by warm and generally dry clear summers and mild, humid winters. This climate is controlled by the moderating effects of the Pacific Ocean, compounded with the rain-shadow effects of the Olympic and Vancouver Island mountains (fig. 1) and the shielding effect of the Coast and Rocky mountains from westerly moving cold, continental and Arctic air (Schaefer, 1978).

There are two dominant soil types in the southeastern Vancouver Island area. One is the Dystric Brunisol, found mainly on the southeastern coast of Vancouver Island and in arid forested areas of the Gulf Islands, the other is the Humo-Ferric Podzol found at higher elevations and under slightly more humid conditions than the Dystric Brunisol (Agriculture Canada, 1987). Vancouver Island is considered to be within the Moist Unsaturated Soil Regime which is characterized by varying periods and intensities of water deficiency during the growing season (Lavkulich and Valentine, 1978). There is an annual growing season (number of days with temperatures >5 °C) of 200 to 240 degree days (Lavkulich and Valentine, 1978).

Vegetation associated with the "Transitional Cool Mediterranean Climate" (van Vliet *et al.*, 1991, p.8) of southeastern Vancouver Island and the Gulf Islands is commonly known as the Coastal Douglas Fir Zone (Jones and Annas, 1978). It ranges from sea level to 450 meters above sea level and is dominated by the coastal Douglas Fir (*Pseudotsuga menziesii var menziesii*). Many other coniferous species are present, however, including: Grand fir (*Abies grandis*), western red cedar (*Thuja plicata*), shore pine (*Pinus contorta*), Sitka spruce (*Picea sitchensis*), and western hemlock (*Tsuga heterophylla*). In addition, some deciduous trees inhabit the Coastal Douglas Fir Zone such as: red alder (*Alnus rubra*), broad leaf maple (*Acer macrophyllum*), northern black cottonwood (*Populus balsamifera* subsp. *trichocarpa*) and the western flowering dogwood (*Cornus nuttallii*) and in

particularly on dry and/or rocky sites Garry Oak (*Quercus garryana*) and Pacific Madrona (*Arbutus menziesii*) thrive (Jones and Annas, 1978).

The shrub layer of vegetation is characterized by salal *(Gaultheria shallon)* and Oregon grape (*Mahonia nervosa*) but numerous herbs, mosses and ferns can also be found in the under-story, while areas disturbed by fire, logging, grazing and urban activities are usually first settled by pioneering species, such as: fireweed (*Epilobium angustifolium*), common gorse (*Ulex europaeus*), Scotch broom (*Cytisus scoparius*), and American stinging nettle (*Urtica dioica* subsp. *gracilis*) (Jones and Annas, 1978).

METHODOLOGY

Mapping

Initial air photo interpretation, using 1982, 1:58,000 air photos (NTS - 92B/5,6,11,12 and 13), was conducted prior to field work during the 1992 summer field season. These photos provided the most comprehensive and least urbanized view of the southeastern Vancouver Island area. Following air photo interpretation, all accessible roads were driven and where surficial sediments were exposed they were investigated and their unit properties described. Of the hundreds of exposures examined only twelve contained extensive stratigraphic information. These twelve stratigraphic sections were described in detail. Mapping was completed during the 1992 field season. Section work was completed during the summer of 1993.

Descriptions of map units and the mapping symbols are based on surficial mapping conventions and definitions from Grant and Newell (1992) and Howes and Kenk (1988). Units are identified by their interpreted genetic origin, preceded by their general clast texture, and followed by a character representing overall surface expression as seen in figure 8.

Field Methods

Section Descriptions

Sections were divided into units according to sediment type. Unit descriptions included thickness, prominence, oxidation and overall colour. Colour was measured with the Munsell colour chart (Munsell, 1975). The large clast content (pebbles and larger) and matrix

texture (smaller than pebble size) was first estimated for till while in the field (see Hand versus Sedigraph texturing table 1), to help establish flow regimes. To assist in the determination of till provenance, facets and striations were measured and large clast lithology was identified.

Figure 8 : Mapping Conventions

Terrain Unit Letter Notation

genetic designation — texture — **gFt** — surface expression

Composite Units

Cv / Mb The component (Cv) above the symbol stratigraphically overlies the one below (Mb)

Mb/R The component (Mb) in front of the symbol is more extensive than the one that follows (R)

Genetic Origin

C	Colluvium
F	Fluvial
F^G	Glaciofluvial
L	Lacustrine
L^G	Glaciolacustrine
M	Morainal
O	Organic
boulders)	
R	Bedrock
structure)	
W	Marine
W^G	Glaciomarine

Texture

c - clay	(<.002 mm)
$ - silt	(.002 - .062 mm)
s - sand	(.062 - 2 mm)
p - pebbles	(2-64 mm)
k - cobbles	(64 - 256 mm)
b - boulders	(>256 mm)
g - gravel	(a mix of pebbles, cobbles and
d - diamicton	(a deposit of variable texture and

Surface Expression

b - blanket	(a mantle of unconsolidated materials > 1 meter thick)
v - veneer	(a mantle of unconsolidated material 10 centimeters to <1 meter thick)
f - fan	(a segment of a cone with a slope of up to 15 degrees)
h - hummocky	(hillocks and hollows, irregular in plan)
t - terraced	(step-like topography)

To evaluate depositional environments, sediment sorting and grading, organic content, clast size, shape and rounding (Zingg, 1935) were described. Clast imbrication in diamictons was measured (Harrison, 1957) to aid in the determination of provenance. In fluvial sediments primary sedimentary structures, such as stratification, bed thickness, paleocurrent indicators and the abundance and shape of sand and gravel lenses were described. Secondary structures

such as loading, dewatering and deformation features were noted, as were vertical and horizontal partings to aid in determining sedimentary environments. Lithologic, textural and radiocarbon samples were collected for detailed laboratory analysis. These features, combined with information on morphology, induration, compaction, cementation, seepage and unit contacts (Rutter, 1991) were used in the lithostratigraphic characterization of each unit.

Pebble Fabrics

Pebble fabrics were taken in diamicton, to determine depositional origin and/or flow direction. Using Harrison's methodology (1957), a minimum of 25 pebble orientations (Domack and Lawson, 1985) were measured at each of the 13 sections. These measurements were taken from the middle of the measured unit, within a one meter square area (Harrison, 1957). Drake (1974) noted that of Zingg's (1935) four shape classes (prolates, blades, discs and spheres) a-axis parallel orientations in diamictons are: strongest using prolate clasts, good using blades and poor using discs and spheres. Measurements of trend and plunge were taken on the long or a-axis of prolate and blade shaped clasts, where a:b axis ratios were at least 3:2. Near vertical or horizontal clasts were avoided for lack of an accurate trend. Measured clasts ranged in size from small pebbles to cobbles (0.005 meters to approximately 0.03 meters).

For visual imaging and statistical analysis of fabric data, three computer programs were employed. 'Rosy' (McEachran, 1987) was used to show two dimensional vector images of trend, 'Stereo' (RockWare Inc., 1992) was used to represent plunge and trend as a contoured stereonet projection, and Ternary Plot (Zippi, 1991) was used to compare relative lithologic and textural percentages. In addition, 'Stereo' (RockWare Inc., 1992) calculated the normalized eigenvalue (E1) and the mean lineation and plunge on the fabric data. Eigenvector (E1) represents the probability, by per cent, that the mean lineation shows true trend (E1 = 0.99) or a random cluster of points (E1 = 0.33). The eigenvector is thought to be statistically significant with 20 measurements or more (Mark, 1973; Mark, 1974; Rutter, 1991;).

Lithology

Data from section descriptions, such as striated clasts, dropstones, fabrics and the lithology of glacial erratics were evaluated to establish the genetic origin of diamictons. The term till was applied to material with known glacial origin and the term diamicton

used for debris flow units or those of unknown origin. To assist in the determination of till provenance, a minimum of 50 medium pebbles to boulders (16 mm to 600+ mm) were sampled from each till unit and either broken and identified in the field or collected and identified in the lab. The procedures used to determine distinguishing lithologies to differentiate diamictons and establish provenance included an evaluation of the bedrock geology of southern Vancouver Island, coastal British Columbia and Washington State. To aid in the determination of possible sources, ice directional indicators, such as striae, drumlins, flutings and roches moutonnées, were plotted on the Quaternary geology maps of southeastern Vancouver Island.

Bedrock geology (see physiography) of the Pacific Northwest shows that although diorites and rare granitoids (granitic and granodioritic rocks) are found on southern Vancouver Island, they are not as abundant as throughout the Coast Mountains (Cordilleran range), where bedrock is dominantly granite and granodiorite. The abundance of granitoid lithologies are thus used to determine Cordilleran provenance (appendix B). Similarly, though minor concentrations of sedimentary, volcanic and metamorphic bedrock units are found throughout the mainland coast, the dominance of these rock types, on southeastern Vancouver Island and around the Georgia Depression is used to help determine Vancouver Island provenance. Diorite is present on both Vancouver Island and throughout the Coast Mountains but it's dominance within the Cordilleran range is used to visually skew, or weigh Cordilleran samples on ternary plots (fig. 9a). Sedimentary lithologies were plotted to determine if rocks from the Nanaimo Sedimentary complex could be used to determine Georgia Depression provenance, however, these results appeared too clustered to be conclusive (fig. 9b).

Laboratory Methods

Grain Size Analysis

Coarse fragment grain size analysis, and Sedigraph preparation, included cleaning, drying, sieving, and weighing. This was conducted by the author in the Quaternary laboratory of the Department of Geology; Sedigraph analysis of the clay, silt and fine sand fraction was done in the Department of Geography at the University of Alberta.

Figure 9a: The Lithology of Southeastern Vancouver Island Diamictons

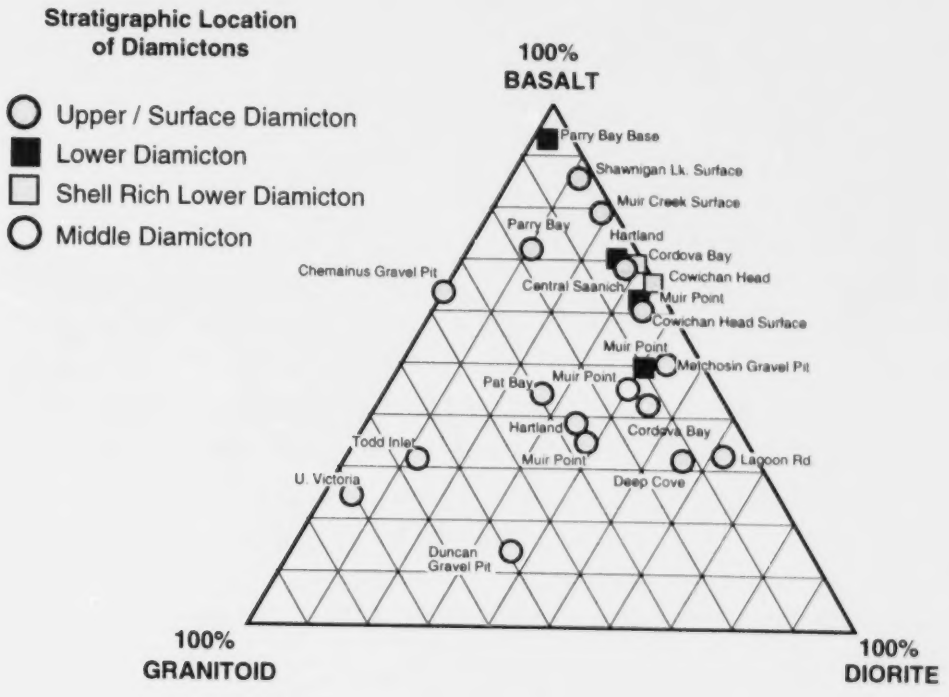
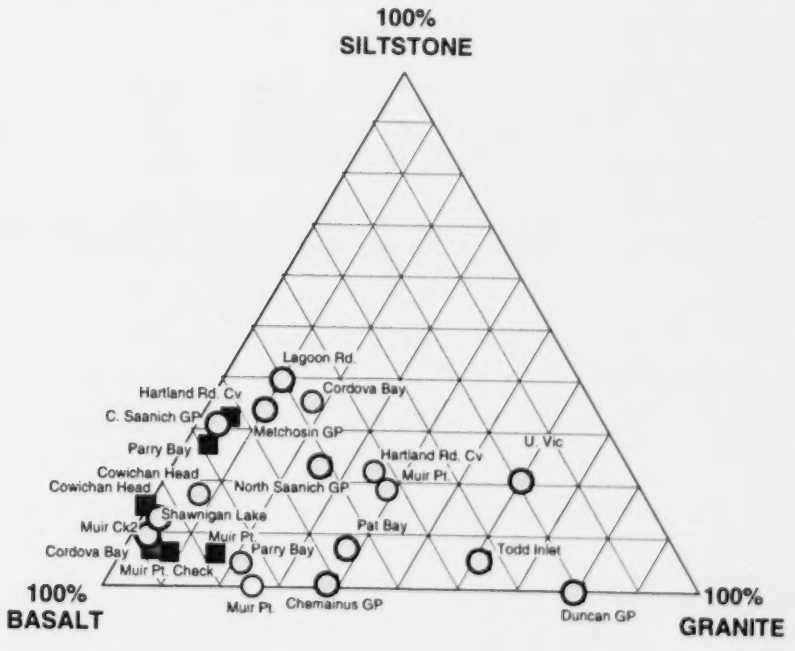


Figure 9b: Lithology of SEVI, testing siltstone



Sieve and Sedigraph Analysis:

Two to three kilogram diamicton and silt samples were taken from within a one meter radius of the centre of the unit being described. Samples were broken by hammer or hand and air dried for up to eight months. Organic macro fragments were removed by hand. Representative sub-samples of 150 to 300 grams were separated from each sample as described in McKeague (1981). The material was then hand ground in a porcelain mortar; initially with a porcelain pestle and later with a rubber tipped pestle, until no aggregate clasts were visible.

Sieving was used to separate the various grain size fractions. Grain size divisions were based on the Wentworth grain size classification (Wentworth, 1922). Each 150-300 gram sub-sample was weighed to the nearest one one-hundredth of a gram, poured into the top of a sieve stack, and shaken for sixteen to eighteen minutes (McKeague, 1981). The sieve sizes (U.S. Standard sieves sizes: 4, 10, 40 and 230) correspond to the Wentworth grain size classification divisions as follows: pebble and larger; granule to pebble; medium sand to granule; and very finesand to medium sand respectively (Wentworth, 1922). Materials finer than those trapped by the #230 sieve included the silt and clay fraction.

The material recovered from each sieve and pan was weighed to determine per cent by size fraction and amount lost during processing. If the total amount lost during processing exceeded 1.5 grams the procedure was repeated on a fresh sub-sample (McKeague, 1981). Material finer than #230 sieve, the silt - clay fraction, was weighed and analyzed by Sedigraph.

Sedigraphic analysis was conducted using a SedoGraph 5100 v3.01. Grain sizes from clay to fine sand which passed through the #230 sieve were measured. Material greater than the #230 sieve that managed to pass through the #230 sieve was added to the medium sand data. This error between the sieve data and the Sedigraph data is the main analytical break in grain size analysis and has lead to a higher clast content in the medium sand range and a slightly lower content in the silt range. The results of sieving and Sedigraphic procedures were totaled and compared to the original sub-sample weight (Appendix C).

Hand Versus Sedigraph Texturing:

Hand texturing accuracy was assessed by comparison with Sedigraph results of duplicate samples (table 1). Hand texturing tends to over-estimate the fine clast fragment and should be noted when viewing the stratigraphic section descriptions.

Table 1: Hand Versus Sedigraph Matrix Texturing

sample #	Hand Textured	Sedigraph Texture
HB92-S28-2:	clay 5-10% silt 20-30% fine sand 20-35% medium to coarse sand ~25%	clay 4% silt 17% sand 78%
HB92-S35-4:	fine sand 5% medium sand 25% coarse sand 70%	clay 4% silt 15% sand 81%
HB92-S32-2:	clay 2-5% silt 20% fine med. sand 70% coarse sand 5%	clay 19% silt 19% sand 62%
HB92-S33-6:	clay 15% silt 30% fine sand 20-30% medium sand 30%	clay 10% silt 13% sand 77%
HB92-S52-1:	clay 2-5% silt and fine sand 30-40% medium sand 35% coarse sand ~20%	clay 3% silt 18% sand 79%

Radiocarbon Analysis

Wood samples collected from the three sections on southeastern Vancouver Island were dated using radiocarbon analysis. Analysis was conducted by Dr. Dave Arnold at the Isotopes Laboratory, Alberta Environmental Centre, Vegreville (AECV) using a scintillometer. Ages are ^{13}C corrected relative to 1950 AD using Libby's ^{14}C half-life, where T(1/2) equals 5568 years (L. D. Arnold pers. comm., 1993). Delta 13 error is 0.3 and stated error probability is one standard deviation (68%). All samples were pretreated using NaOH (to remove any mobile humic acids) and HCl (to remove carbonate contaminants). The Delta ^{13}C correction applied is 16 (Delta C13 + 25) years (Arnold, 1995). The Delta ^{13}C values are per mil relative to the PDB international standard (L.D. Arnold pers. comm., 1993). All the dates in this thesis are radiocarbon ages in years before present (y BP) relative to 1950 AD.

Each of the three dates collected for this thesis appear to push the limits of conventional ^{14}C dating (39,860 +/- 2800 (AECV #1732C); 40,800 +/- 2600, (AECV #1869C), and 40,800 +/-3400, (AECV #1868C)), however, they remain within the generally accepted bounds, < 45,000 y BP, for this dating technique (Arnold, pers. Comm., 1996). Moreover,

stringent collection methods and sufficient proxy evidence further support the reliability of these dates.

The 39,860 +/- 2800 y BP date was obtained from the core of a large, well preserved piece of wood (25 x 6 x 2 cm) found in an unoxidized silt, at least 10m from modern organics at unit 5, Parry Bay (figure 25). The sample was taken 0.20 meters in from the face of the section, from a landslide head scarp exposed five months prior to sampling, using a knife and plastic bag. This date is further corroborated by similar dates obtained in stratigraphically equivalent organic rich sediments at Muir Point and Cowichan Head (Unit E, figure 25), optically dated as younger than ~68,000 y BP (Hicock pers. comm. 1995, unit 6 at Muir Point). In addition, unit 5 is stratigraphically equivalent to two conventional radiocarbon dates from unit 6 at Muir Point (43,600 +/- 600 y BP, GSC 3295) and unit 5 at Cowichan Head (35,600 +3000/ - 2000 y BP, Dyke et al. 1965).

Two ~40, 800 y BP dates were derived from wood found 20 - 30 cm above the lower contact of Unit 7 at Muir Point (figure 25). Both samples of wood were found approximately 100 meters apart within a silty/sandy diamicton directly above an organic silt. The apparently uncontaminated samples were taken 15-30 cm in from the seacliff face. Validity of these dates is supported by the agreement of the dates for both samples, their stratigraphic position directly above optically dated (68,000 y BP; Hicock pers. comm. 1995), and radiocarbon dated (43,600 +/- 600 y BP, ^{14}C, GSC 3295) organic rich sediments.

Optically-Stimulated Luminescence Dating

The process of optically-stimulated luminescence dating (OSL or optical dating) was introduced by Huntley *et al.* (1985) and works on the principle that impurities and structural defects in minerals act as traps for free electrons expelled by the decay of naturally occurring radioactive elements, and that the number of trapped electrons increases with time (Lian et al. 1995). Such naturally occurring radioactive elements include: uranium and thorium, which produce alpha radiation, and potassium (^{40}K), which produces beta and gamma radiation. It is the interaction of alpha, beta and gamma radiation with cosmic-ray radiation and matter which produces the free electrons that become trapped within the mineral defects (Wintle, 1993).

Optical dating takes advantage of the electron traps within minerals that empty most readily with exposure to sunlight, and which dominate the luminescence under the optical excitation of an argon laser (Lian et al. 1995). This method has been shown to be capable of providing ages consistent with other methods (Huntley et al., 1985; Smith et al., 1990; Stokes and Gaylord, 1993; Lian et al., 1995). It should be noted, however, that although dates from the Muir Point section strongly support the previously hypothesized chronology (Lian et al., 1995), optical dating is a relatively new technique and tests for error in methodology, as well as comparison tests on material of known age, are relatively scarce (Lian et al., 1995).

RESULTS

Surficial Geology

Most of the surficial materials on southeastern Vancouver Island were deposited from the onset of the last glaciation to when sea level became relatively stable after ice withdrawal. The 1:50,000 scale maps completed for this research show the distribution of deposits on southeastern Vancouver Island (Appendix F; Blyth and Rutter, 1993 a, b, c, and d; Blyth, *et al.*, 1993; and Rutter and Blyth, 1993; in map pocket). The following descriptions outline the distribution and characteristics of the mapped surficial materials followed by the map symbol in brackets (Refer to Appendix F for detailed maps or fig. 10 for a generalized surficial geology map). These surficial materials are first described according to their morphological and textural characteristics, followed by their general distribution and finally their distribution across each map area. Following the description of surficial sediments across southeastern Vancouver Island, a summary of the stratigraphic distribution of sediments is discussed and interpreted.

Bedrock (R)

Bedrock includes outcrops of in-situ rock, and rock covered by less than ten centimeters of unconsolidated sediment. On southeastern Vancouver Island bedrock is exposed at actively eroding coastal headlands all around the field area and at elevations greater than the maximum marine high stand of approximately 85 meters above sea level around Victoria area where processes of erosion are more dominant than those of deposition (fig. 11). Exposures of bedrock comprise less than eight per cent of the total field area, though its inclusion into many areas of colluvial veneer suggests this is a low estimate.

Figure 10: Generalized Surficial deposits of Southeastern Vancouver Island

Figure 11: Major Bedrock Outcrops on Southeastern Vancouver Island

Colluvium (C)

Colluvium is identified in the area by its unconsolidated nature, its numerous angular and local clasts and its lack of, or crude, stratification. It includes talus, avalanche debris, landslide debris, and other mass wastage products, as well as weathered bedrock. Reworked till is interpreted as colluvium when found to contain numerous angular, local clasts and/or shows signs of stratification and poor induration. Colluvium is found as blanket or veneer (Cb, Cv) in bedrock pockets, valley bottoms or on steep valley walls throughout southeastern Vancouver Island and the Gulf Islands (fig. 12). It dominates upland areas above the marine high stand (Clague, 1975) and comprises approximately fifty per cent of the field area.

Morainal Deposits (M)

Morainal deposits on southeastern Vancouver Island, consist of 1 to 12 meters of moderate to well-compacted, silty to sandy till ($dMb to sdMb), draped across gently rolling upland depressions, and coastal and valley lowlands. Morainal veneers (Mv) consist of remnant pockets of till less than one meter thick, and can be found almost anywhere till was deposited and processes of erosion are slow (fig. 13). Morainal deposits comprise approximately forty per cent of the field area.

Texturally the surface tills vary considerably, from the silty tills ($dMb) around the lowlands of Victoria, the Saanich Peninsula and west of Crofton and Ladysmith, to the locally dispersed outcrops of sandy, poorly bedded diamicton (sdM) found throughout southeastern Vancouver Island, notably at Cordova Bay, the Trio and Butler Brother's gravel pits, the University of Victoria, and on top of Cowichan Head. The silty tills are characterized by a matrix of 10-40 per cent clay, 40-50 per cent silt, approximately 10 to 15 per cent fine to medium sand and less than 5 per cent coarse sand. Clast content ranges from 30 per cent at the surface to 5 per cent at the base of the deposit. Clasts range in size from 0.1 to 1.0 meter in diameter. Silty diamictons tend to be well indurated and grey, to dark greyish brown (2.5Y 4/2, moist). The dominant clast lithologies, in order of abundance are: plagioclase porphyry, granite, quartzite, sandstone, siltstone and basalt. From lithological and striae data, this till appears to have both Vancouver Island and Coast Mountain sources and its fine matrix is generally found in association with underlying bedrock or glaciomarine deposits.

Figure 12: Major Surficial Deposits of Colluvium

Figure 13: Major Morainal Deposits

VANCOUVER
ISLAND
MTNS.
SOOKE HILLS
SAANICH PENINSULA
VICTORIA
COLWOOD
METCHOSIN
SOOKE
LANGFORD
SAANICH
MAPLE BAY
CROFTON
CHEMAINUS
LADYSMITH
Galiano Island
Saltspring Island
Pender I.
Saturna I.
Tumbo I.
Morsby I.
Coal I.
Sidney I.
James I.
Cowichan Head
Trio Gravel Pit
Cordova Bay
Beacon Hill
Parry Bay
Muir Pt.
Goldstream Pit
Metchosin Gravel Pit
Esquimalt Lagoon
Portage Inlet
Whitty's Lagoon
Sooke Basin
Diversion Reservoir
Prospect Lk.
Shawnigan Lake
Cowichan Bay
Saanich Inlet
Cowichan Valley
Chemainus R.
Koksilla R.
Jordan R.
Sooke R.
Clapp Ck.
Muir Creek
Kuper I.
Thetis I.
Chemainus Reserve
Gravel Pit
Mill Bay
Shawnigan Lake
Sooke Lake
Neal Lake
Prevost I.
N. Pender I.
S. Pender I.
DEEP COVE
N. SAANICH
Oyster Bros.
Qualicum Lake
Somenos Lk.
Cowichan Lake
Ford Valley
Mud Bay
Cv//Cb
Cv
Cb//Mb
Cv//Mv
Mb//Cb
Mb//Cp
Mb//Op
Mb//Fb
Cb//Cv
Cv/R
Mb/My
Cv/Mb
Fb
Op
FG
FG/Mb
Cb/WG
Mb/Cb
Mb/Cp
Mb/Op
Mb/Fb

The sandy tills are characterized by a matrix of 0 to 2 per cent clay, 0 to 5 per cent silt, 5 to 20 per cent fine sand and the remainder, medium to coarse sand. Clast content ranges from 15 to 40 per cent and consists of similar lithologies as the silty, surface tills. Colour too, tends to be very similar to that of the silty till. The sandy diamicton is usually found to overlie glaciofluvial deposits, likely as a result of the re-entrenchment of proglacial sand and gravel, such as found above the Trio, Central Saanich and Butler Brother's gravel pits. Sandy diamictons are also found in association with flow till features such as steeply dipping fabrics (appendix D, U. Victoria.), poor consolidation and poor to moderate stratification. Examples of such stratified or inclined diamictons can be found at Beacon Hill, Parry Bay, the University of Victoria, and at Cowichan Head.

Physiographically, morainal units tend to drape and subdue existing bedrock features. The formation of ridged tills (dMbr) found in western Sooke and on the Saanich Peninsula areas (fig. 13) appear to have been formed by two different processes. The rocky western Sooke area exhibits ridged morainal deposits controlled by bedrock jointing, while the more subdued ridges at Muir Point and the drumlins found on the Saanich Peninsula, Sidney and James Islands (fig. 5), are a result of glacial fluting across pre- existing soft sediments. In the north-central portion of the field area, around Ladysmith, and on both sides of the Cowichan Valley (fig. 13), the till forms a hummocky blanket interspersed with bogs (dMbh/$Op) or glaciolacustrine deposits (dMbh/c$L^{G}p). The hummocky nature of these tills suggests that they were likely formed as a result of ice stagnation, possibly as Vancouver Island ice stagnated against a Cordilleran ice dam, or as upland Vancouver Island ice, stagnated against Cowichan Valley and Cordilleran ice masses.

Fluvial Deposits (F)

On southeastern Vancouver Island post-glacial fluvial deposits are represented as flood plains, terraces, deltas and alluvial fans often incised into, or deposited on glaciofluvial deposits. Post-glacial deposits generally consist of silt, sand and gravel ($sgF) and comprise no more than two per cent of the total field area (fig. 14). Fluvial deposits occur where rivers lose potential energy at valley widenings, such as the Jordan River, Bear Creek reservoir and Cowichan Valley, or in a standing water body, such as the Cowichan River delta at Cowichan Bay, the Goldstream River delta/estuary at Saanich Inlet, the Sooke River delta entering the Sooke Basin, and where the Chemainus, and lesser rivers such as Muir Creek, Kirby Creek and Colwood Creek meet the ocean (fig. 14).

Figure 14: Surficial Fluvial and Glaciofluvial deposits on Southeastern Vancouver Island

Glaciofluvial Deposits (F^G)

Glaciofluvial deposits are larger, coarser versions of their post-glacial fluvial counterparts ($sgbF^G$) deposited in sub-glacial esker, or pro-glacial kame, sandur or deltaic environments. Glaciofluvial deposits comprise no more than three to five per cent of the surficial materials on southeastern Vancouver Island (fig. 14). They consist of poorly to well sorted, sub- to well rounded sand and gravel and rare boulders, often deposited as thick, aggradational sequences of steeply dipping (25-28°), or trough cross-bedded sediments. Glaciofluvial features are best exposed at surface at the Metchosin gravel pit and at the Muir/Kirby Creek delta. Glaciofluvial deposits on southeastern Vancouver Island are most commonly found beneath a blanket of sandy till, such as found at the Goldstream, Chemainus, Chemainus Reserve and Duncan gravel pits, and at the mouth of the Sooke River and throughout the Cowichan Valley. Eskers are rare on southeastern Vancouver Island with only two examples being identified approximately five kilometers west of Chemainus (fig. 14).

Marine Deposits (W)

Along the coast of southeastern Vancouver Island sediments deposited in marine waters or along the shore consist of clay, silt, sand and/or gravel. These surficial deposits include post-glacial beach, lagoon and estuarine sediments. Marine deposits compose no more than 0.5 to one per cent of exposed surface deposits in the field area and are dominantly beaches and spits such as found at Cowichan Head, Sidney Island, Whitty's Lagoon, Whiffin Spit and the Esquimalt Lagoon (fig. 15). Marine deposits are also represented by estuarine sediments such as those at the mouth of the Goldstream and Cowichan Rivers, Portage Inlet (fig. 15) and throughout the intertidal zones on southeastern Vancouver Island. Most estuarine deposits were too small to be mapped at the scale of this research.

Glaciomarine Deposits (W^G)

Glaciomarine deposits (W^G) are rarely exposed at surface and probably represent no more than 0.5 per cent of the surficial deposits on southeastern Vancouver Island. These deposits are similar in origin and appearance to modern marine deposits on southeastern Vancouver Island in terms of their massive, to poorly bedded, structure formed as clay minerals flocculate and settle in the saline environment at a similar rate to silt (Sposito, 1989). They contain shells and many of the signs of bioturbation that modern marine deposits hold, yet to a lesser extent. Glaciomarine deposits are particularly characterized in the study area by inclusions of oversized drop-stones and glacial erratic material not found in marine sediments. In the study area glaciomarine sediments are usually found in

Figure 15: Major Marine and Glaciomarine Surficial Deposits on SE Vancouver Island

association with modern marine deposits, as at Portage Inlet near Victoria, however, they are more often represented around Victoria and the Saanich Peninsula by a, likely glaciomarine, silty diamicton ($dMb) which grades at depth, to shell-rich, bluish, silty-sand of a glaciomarine origin (fig. 15).

Organic (O)

Organic deposits occur as post-glacial infill in hummocky tills and in bedrock controlled depressions, such as the Heal Lake section and Rithet's Bog, near Victoria (fig. 16). Organic deposits are represented by features such as bogs, fens, swamps, flood-overbank and above-tide marshes. and which comprise no more than two per cent of the surficial deposits on southeastern Vancouver Island (fig. 16, Op only). Organic deposits often occur in association with lacustrine and glaciolacustrine deposits as found within the hummocky tills near Ladysmith, Cowichan Valley and Parry Bay (dMbh/$Op) (fig. 16). Organic deposits on southeastern Vancouver Island consist of decaying vegetative matter and detrital wood and often lack tree cover due to poor drainage.

Lacustrine Deposits (L)

Lacustrine deposits, as with organic deposits, occur as post-glacial infill in hummocky moraine or bedrock terrain and consist of sand, silt and clay, and rare beach sand and gravel deposits. Most lacustrine deposits on southeastern Vancouver Island are found in regions of hummocky bedrock (e.g. Heal Lake (Rh//csLp) or within the hummocky tills near Ladysmith, Sooke and Shawnigan Lakes, and Goldstream (Mbh/Op). Unless identified in the field, lacustrine deposits are rarely marked on maps due to the succession of organic infill (Op) over lacustrine sedimentation.

Glaciolacustrine Deposits (L^G)

Glaciolacustrine sedimentation associated with (or deposited in near-contact with) glacial ice is similar to post-glacial lacustrine material except that it displays slump structures, drop-stones, and may be found in association with kettled topography. In section, glaciolacustrine deposits can be differentiated from glaciomarine deposits on southeastern Vancouver Island by their excellent bedding and their lack of bioturbation. Since post-glacial lacustrine and organic material often infills glaciolacustrine basins, glaciolacustrine features (c$$L^G$) are only identified on the accompanying maps when a glacial influence is identified in section. Surface deposits of glaciolacustrine materials can be found on the north and south sides of the Cowichan Valley, across the pitted, Colwood delta from Goldstream

Figure 16: Major Lacustrine, Glaciolacustrine and Organic Surficial Deposits

to Colwood, and associated with many of the organic plains throughout the field area (fig. 16).

Glacial Deposit Characteristics and Till Provenance

To evaluate the stratigraphy of southeastern Vancouver Island, the physical properties of individual units within all sections, were described (appendix A), with particular attention paid to glacial deposits and their indicators of provenance (i.e. lithology (appendix B), texture (appendix C) and fabric (appendix D)). The following sections review the lithologic and textural characteristics of the various tills to help establish their provenance. This is followed by a description of ice flow directional indicators including, till fabric, bedrock striae, as well as bedrock and sediment fluting, to corroborate provenance evidence.

Till Lithology

In order to establish the origin of tills on southeastern Vancouver Island, possible source areas had to be identified. The possible source areas include: Vancouver Island, which is dominated by volcaniclastic breccias, sub-marine and sub-aerial basalts, limestones, clastics, and cherts, (Massey, 1994; Yorath, 1992; Yorath, 1988; Muller, 1982); the Cordilleran or Coast Mountains of British Columbia and Washington State, which are primarily granite and granodiorite (Gabrielse and Yorath, 1992); the Georgia Depression, which has a bedrock base of shale, mudstone, sandstone and conglomerate (Yorath, 1988); and the Olympic Mountains of Washington State, which are geologically comparable to southeastern Vancouver Island with their high concentrations of marine sedimentary and basaltic rocks (McKee, 1972). As lithologic differentiation of Olympic Mountain and Vancouver Island tills was beyond the scope of this thesis, and ice flow directional indicators suggested surface and sub-surface tills to have northerly, easterly and westerly sources (refer to the following section on ice flow directional indicators) the Olympic Mountains of Washington State were eliminated as a source of ice on southeastern Vancouver Island (fig. 23 and appendix D).

To help establish the origin of tills on southeastern Vancouver Island, given the complex nature of the bedrock geology (Muller, 1982; Yorath, 1988; Yorath, 1992; Massey, 1994), till provenance was interpreted from the abundance of one rock type (or suite of rocks) over all others. The rock types chosen to represent the three possible source areas for tills in the field area, are those lithologies which dominate the three source areas. The

lithologies chosen are: granite and granodiorite (granitoid), which best represented the Cordilleran/Coast Mountains of British Columbia and Washington State; basalt, which dominates the bedrock geology of southern Vancouver Island; siltstone, which dominates the Georgia Depression. In addition, diorite, which can be found both on Vancouver Island and throughout the Coast Mountains was used to test whether it was more prevalent in basalt rich samples or granitoid rich samples and to prevent clustering of data points along the basalt/granitoid ternary diagram axis (fig 17).

By comparing the concentrations of the three indicator lithologies found in surface and subsurface tills (fig. 17), it became apparent that a wider range of determinant lithologies could be found in surface tills than in subsurface tills from the same location. Surface tills contain from 14 to 86 per cent basalt, 0 to 63 per cent diorite, 0 to 40 per cent siltstone and from 3 to 70 per cent granitoids (fig. 9). In contrast subsurface tills contain from 50-95 per cent basalt, 25-45 per cent diorite, 5-32 per cent siltstone and no more than 0-10 per cent granitoids. In addition, upper tills, such as those at Cordova Bay, Parry Bay and Muir Point, contain a higher percentages of granitoid and dioritic rocks than lower tills in the same area (fig 17 and Appendix B). This increase in granitoid lithologies in the upper tills is interpreted to be due to an increased influence of Cordilleran ice during the last glaciation. However, some of the strongest similarities between till lithologies exist between the lowest tills at Cowichan Head, Cordova Bay and Muir Point and the surface tills at Central Saanich, Cowichan Head, Shawnigan Lake and Muir Creek (fig. 17), which exhibit similar concentrations of basalt (50-95%), diorite (25-45%), granitoids (0-10%) and siltstone (5-32%) (fig. 17). Their similarity suggests one of two scenarios:

1) either they were all deposited during the same glacial event and from the same source, or
2) they were deposited by ice with the same source but not necessarily during the same event.

Evidence of non-glacial sedimentation between the glacial deposits in question supports the latter scenario (see the chapter on stratigraphy and sedimentology), whereby these stratigraphically non-equivalent units likely had similar origins. The high concentration of basalt in the lowest tills at Cowichan Head, Cordova Bay and Muir Point and the surface tills at Central Saanich, Cowichan Head, Shawnigan Lake and Muir Creek, appear representative of Vancouver Island bedrock sources. In addition, surface tills tend to be more mafic in the upland areas of southeastern Vancouver Island than in coastal regions (figure 18), likely a result of Vancouver Island ice dominance in upland areas during the last glaciation.

Figure 17: Lithologies of Southeastern Vancouver Island Diamictons

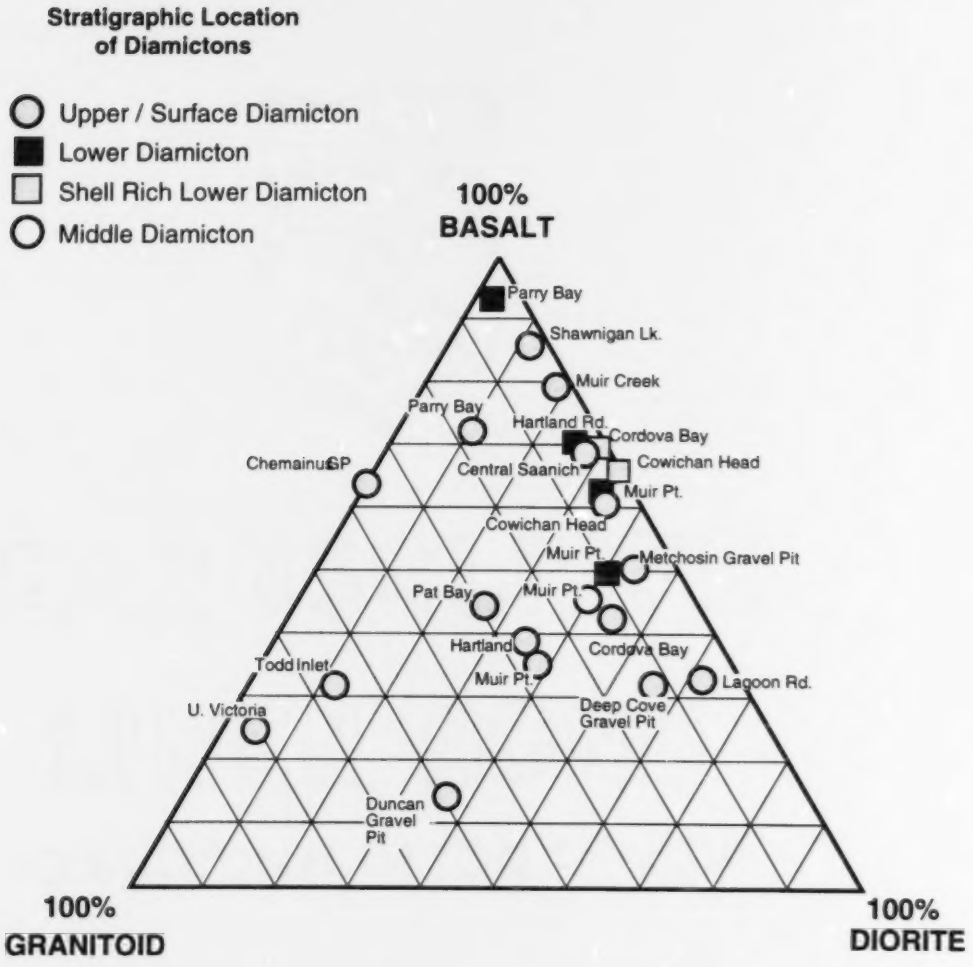
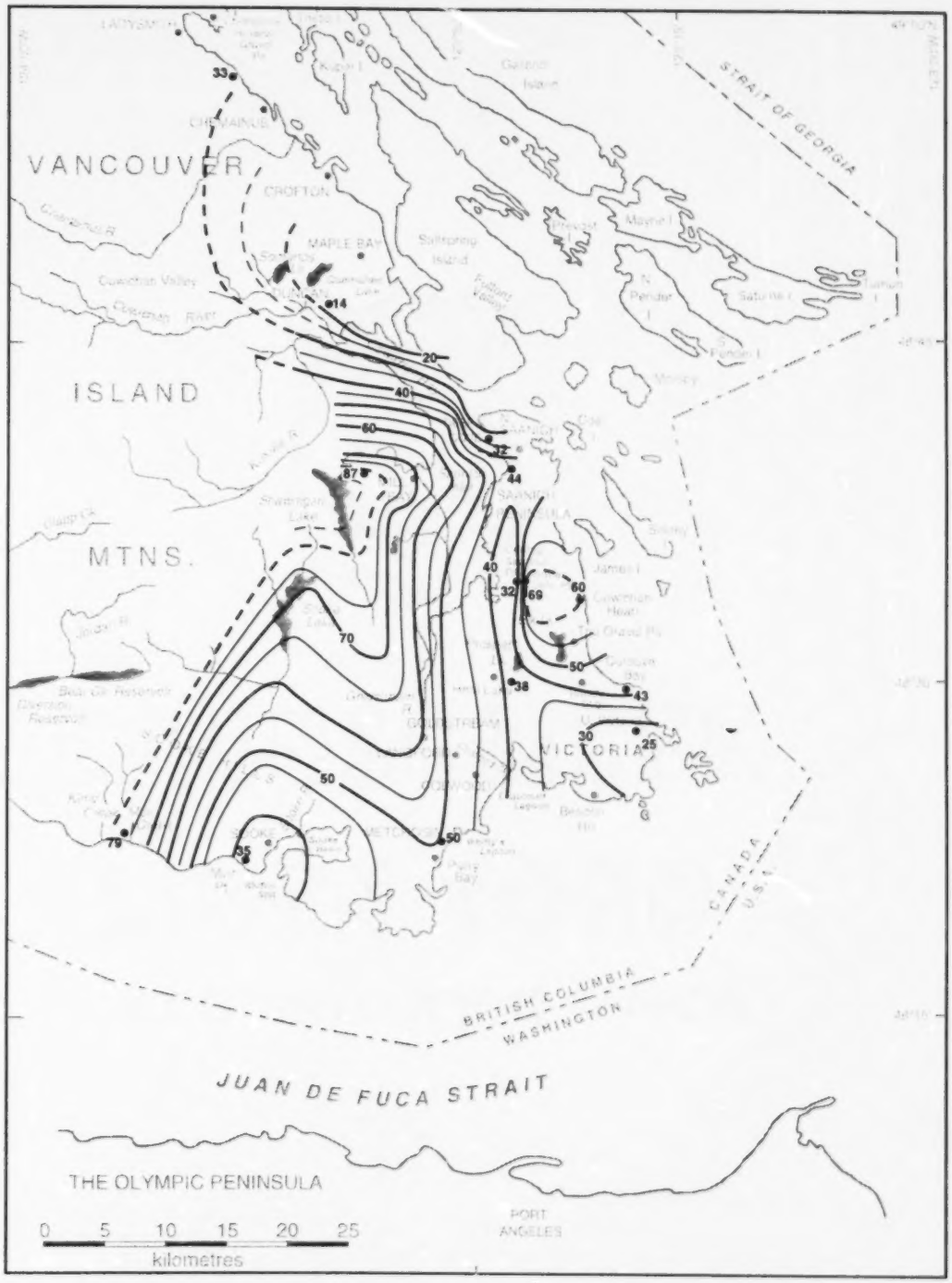


Figure 18: Per Cent Basalt in Southeastern Vancouver Island Surface Tills



Dashed lines represent areas lacking data.

● 25 = Sample location.

Till Texture

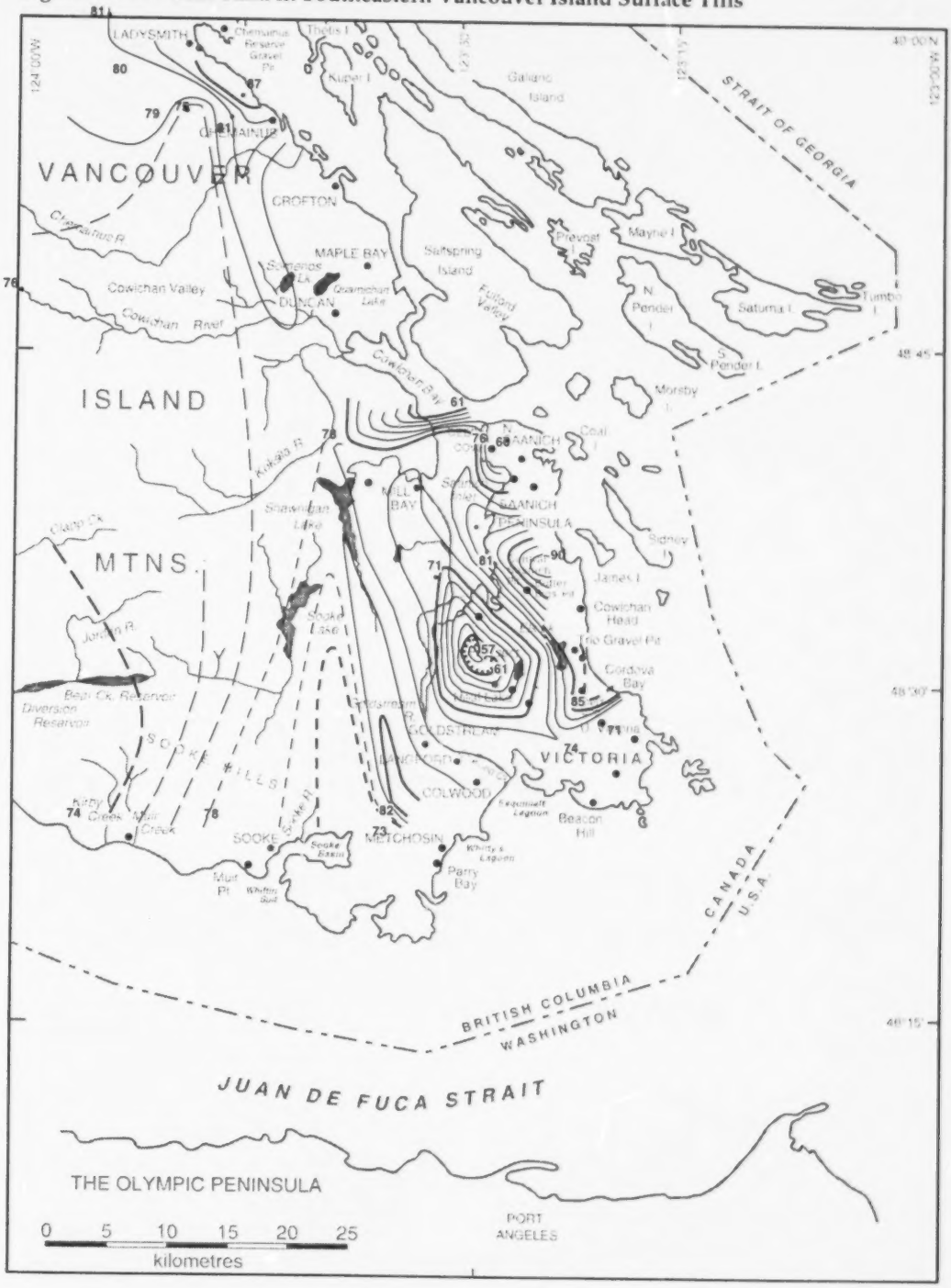
To test if granitic source lithologies were related to coarser till matrices than mafic lithologies on southeastern Vancouver Island, a hand drafted, isoline plot of per cent sand at surface till sample locations was created (fig. 19). This plot was compared to the plot of per cent basalt in surface tills by location (fig. 18) and lithological and textural ternary diagrams (figs. 17 and 20 respectively). Comparison shows that surficial tills low in basalt and high in granitoid and diorite lithologies tend to have sandier texture than those with a high basalt content. However, the sandiest surficial tills were generally found directly overlying, or adjacent to, thick glaciofluvial deposits (fig. 21), while the fine textured tills were found to either overlie bedrock or thick units of glaciomarine material. The result of this comparison is that a correlation between matrix grain size and provenance cannot be accurately determined on the basis of this evidence. A more detailed sampling program of both surface till texture and lithology may resolve this issue.

Variations in texture do, however, help identify facies change. Shell-rich glaciomarine tills, like those found at Cowichan Head (unit 3, fig. 22) and Cordova Bay (unit 1, fig. 22) are more clay rich than subglacial tills such as those at Muir Point (unit 7 fig. 22). Conversely, flow tills, such as found at the University of Victoria, show a distinctively coarser texture (fig. 19, #85) than stratigraphically equivalent subglacial till (fig. 19, #57). Variations in till matrix textures were found to be most useful in aiding the determination of till genesis, than in determining its provenance.

Ice Flow Directional Indicators

In order to help identify possible ice sources, and to determine ice directional movement during the last glaciation, dominant ice flow directional indicators were measured and plotted (figure 23 and Appendix F in map pocket). These ice flow directional indicators include young bedrock striae (i.e. superimposed over older striae), drumlins, flutings, roches moutonnées and fabric. These measurements indicate ice flow direction, yet more notably, their variations appear to show subtle changes in ice flow direction, possible identifying early to advanced stages of ice movement or interactions between Vancouver Island and Cordilleran ice masses during the last glaciation. Bedrock striae and possibly flutings show dominant directions of subglacial ice flow as translated through basal ice onto the rock surface, while fabric appears to indicate ice movement and glacial debris flow activity at the more advanced stages of glaciation. For example, near Ladysmith, striae indicate a southeasterly flow of ice, likely derived from Vancouver Island Mountains, and flowing down slope towards the lowlands of the Georgia Depression. However, a fabric from

Figure 19: Per Cent Sand in Southeastern Vancouver Island Surface Tills



Dashed lines identify areas lacking data.
●71 = Per cent sand at sample location

Figure 20: Textual Plot of Southeastern Vancouver Island Diamictons

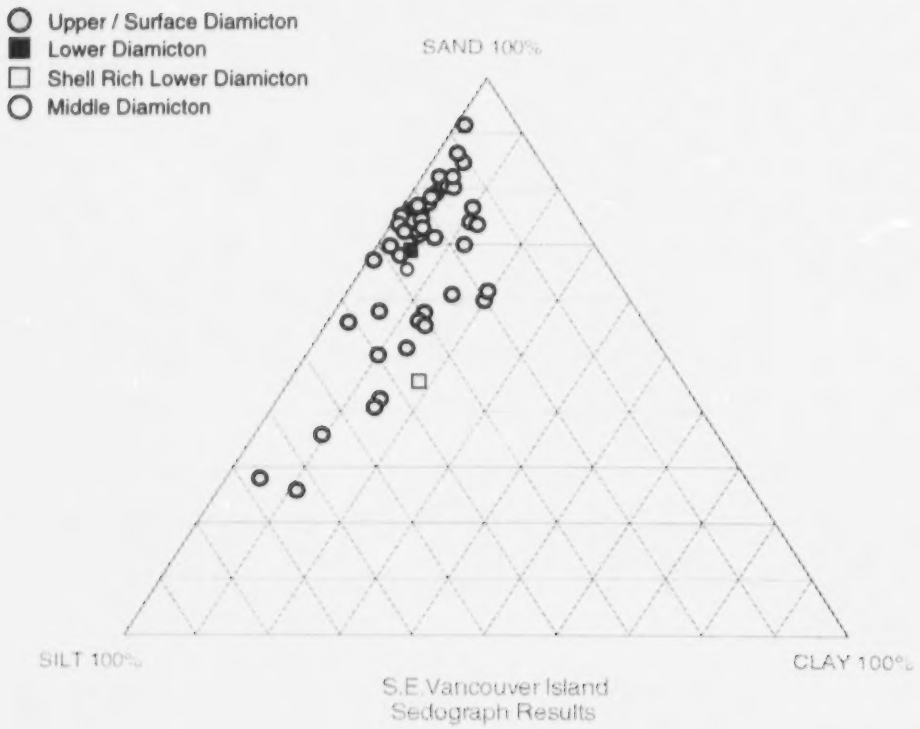


Figure 21: Per Cent Sand in Surface Tills - Showing Substrate Where Known

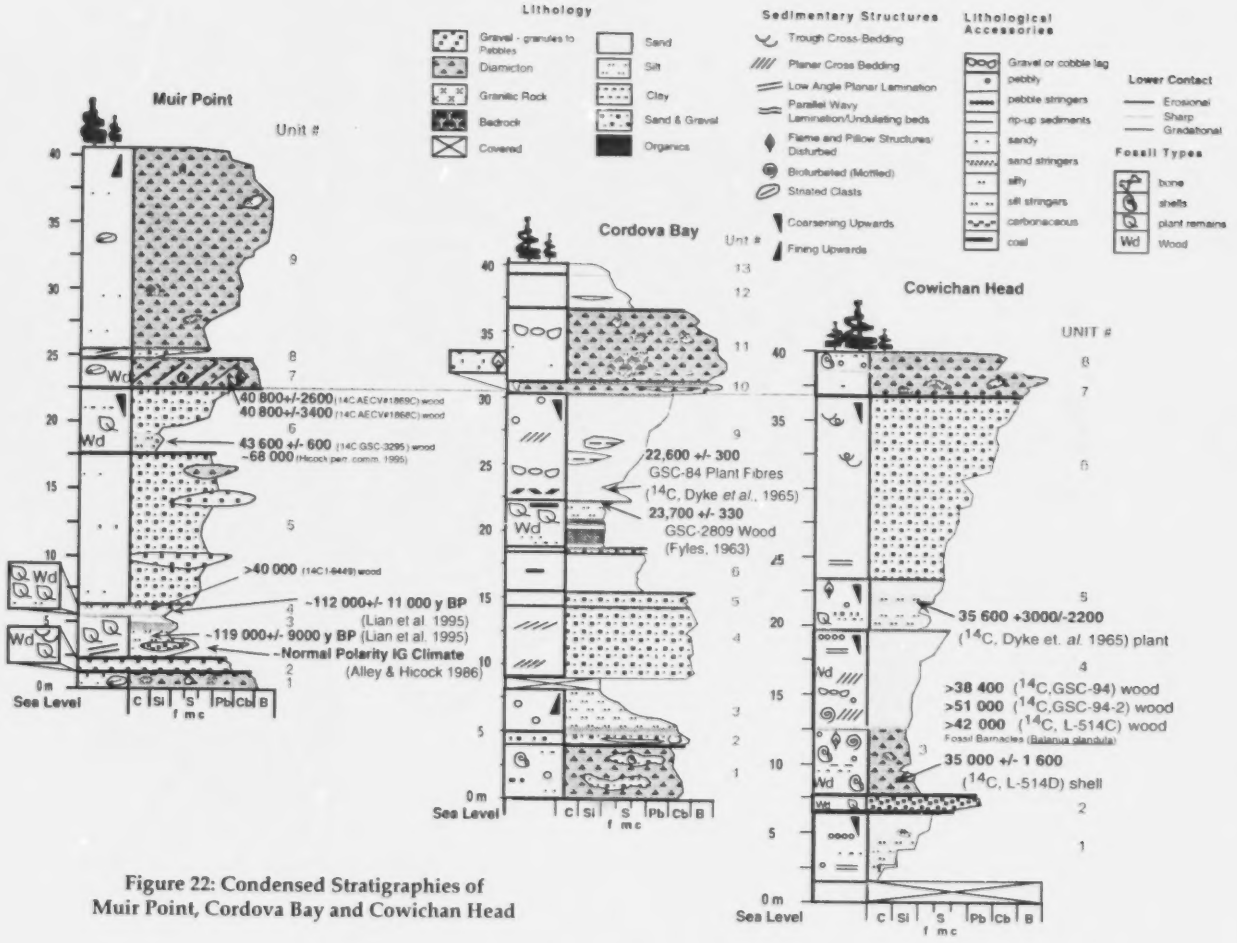
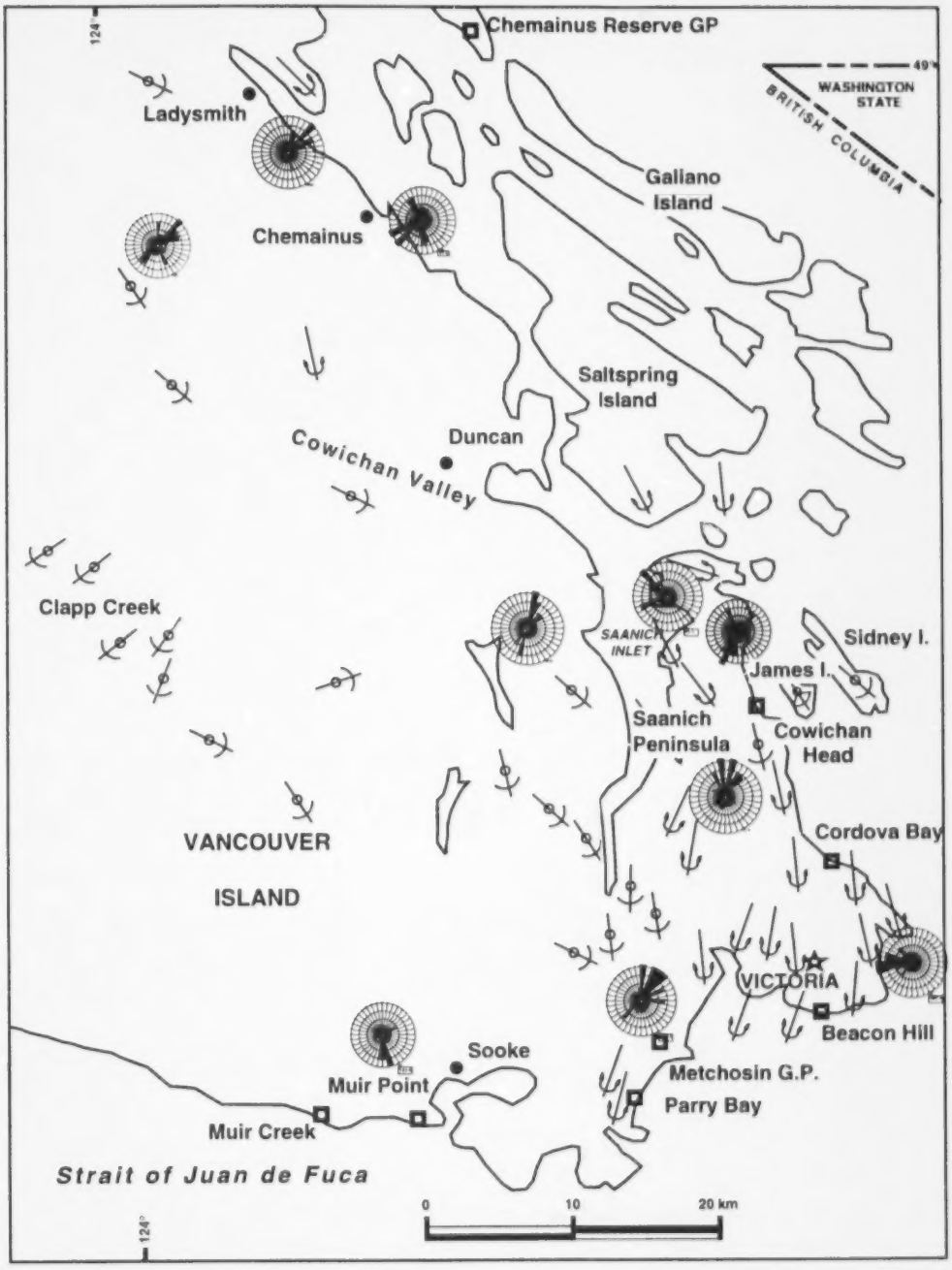


Figure 22: Condensed Stratigraphies of Muir Point, Cordova Bay and Cowichan Head

Figure 23: Ice Flow Directional Indicators of Surficial Tills



Section Location
Town
Capital City

Striations:
Known Direction

Drumlin:
Known Direction

Surface till, fabric directional indicator oriented north.

till overlying this striated bedrock near Ladysmith shows a low angle basal, flow of ice from northeast to southwest. Two possible explanations for this variation in bedrock versus till fabric, ice directional indicators, are that either southeasterly flowing Vancouver Island ice was physically redirected by southwesterly flowing Cordilleran ice, or it was completely overtopped by southwesterly flowing Cordilleran ice. The latter idea appears more likely as there is a diminished Vancouver Island lithologic content up section, in surface tills across southeastern Vancouver Island (fig. 17).

At the University of Victoria, south of Cordova Bay, a similar discordance of ice flow indicators and fabric is identified, however, with a slightly different origin. Bedrock striae indicate a southeasterly to southerly ice movement dominated the Victoria area in the early stages of glaciation while the fabric of surface tills indicates a flow till origin, with an eastern source (fig. 23). The difference between striae data and fabric data in this case, appears to be the result of flow till activity perpendicular to basal ice flow movement (fig. 23). In addition, the off-shore source and high Cordilleran lithologic content of this flow till (fig. 18) suggests a Cordilleran provenance. Only a detailed analysis of lithology and fabric throughout this site could identify the source of the basal till but it does appear that the Victoria area was at one time, during the last glaciation, overtopped by Cordilleran glacial debris. In addition, as both fabric and striae tend to be redirected westward in the Victoria and Metchosin areas, it is likely that Cordilleran ice was extensive enough in the Georgia and Juan de Fuca Straits to actually redirect Vancouver Island ice westward (fig. 23).

Discordant ice directional indicators (i.e. fabric versus roches moutonnées, drumlins, rock striae, and fluting (fig. 23)) combined with lithologic data from surface tills (fig. 18) along the coast of southeastern Vancouver Island, appear to indicate that Vancouver Island ice built up in major island valleys, such as the Cowichan Valley, and flowed towards the lowlands prior to converging with Cordilleran ice in the Georgia Strait. Drumlins in the western-most regions of the field area (in the Clapp Creek area, fig. 23) and morainal deposits across the area, suggest southeastern Vancouver Island to have been overlain by as much as 1524 meters of ice (Halstead, 1966) and from ice flow direction indicators it appears that this Vancouver Island ice moved both southeastward towards the Georgia Depression and southwestward towards the Strait of Juan de Fuca (fig. 23). Ice flow directional indicators also show Vancouver Island ice, from the Cowichan Valley, to have not long shaped the drumlins of James and Sidney Island, off the eastern Saanich Peninsula (fig. 23 and fig. 5), when its path was altered by a much larger force (i.e. the Cordilleran ice

sheet). This is seen in both the redirected bedrock striae patterns in the Victoria area (fig. 23), and in the increasing abundance of granitoid lithologies in the surface diamictons from Cordova Bay and Cowichan Head to Victoria (fig. 18). Although the Olympic Peninsula was excluded as a source of ice on southeastern Vancouver Island, ice from the Peninsula may have played a role in redirecting the Juan de Fuca ice lobe (Alley and Chatwin, 1979) toward the west-northwest, as seen by the west-northwesterly trending basal till fabric at Muir Point (fig. 23).

Stratigraphy and Sedimentology

In the following section, the stratigraphy and sedimentology of southeastern Vancouver Island Quaternary deposits will be discussed. Twelve major Quaternary sections from the area (fig. 24) are described and interpreted in this research (appendix A) and, from the seven most extensive sections (fig. 25), a composite stratigraphy is identified (fig. 26). All units in figure 25 contain their original section description unit numbers (i.e. from appendix A), in addition to their newly interpreted composite stratigraphy, unit letters (A to I'). These letters are arranged from oldest (A) to youngest (I') according to stratigraphic position, the laws of superposition, gross allostratigraphic divisions, lithostratigraphic characteristics and age (fig. 25). Units which display a range of characteristics from one section to another, yet can be stratigraphically and chronostratigraphically placed within a composite unit are correlated with dashed lines and faded letters. If the stratigraphic position is unknown or questionable a 'question mark' (?) (fig. 25) is used to denote uncertainty. In addition, as two of the type sections for southwestern British Columbia exist within the southeastern Vancouver Island area (i.e. the Cowichan Head Formation (Clague, 1976; Armstrong and Clague, 1977); and the Muir Point Formation, (Hicock and Armstrong, 1983)), the established geologic event unit is identified in bold and the interpreted geologic event unit, for correlative units lettered in this research is noted in italics (fig. 25). The composite stratigraphy developed within this chapter (fig. 26) will form the basis of the updated Quaternary history for southeastern Vancouver Island.

Figure 24: Locations of the Twelve Major Sections Around Southeastern Vancouver Island

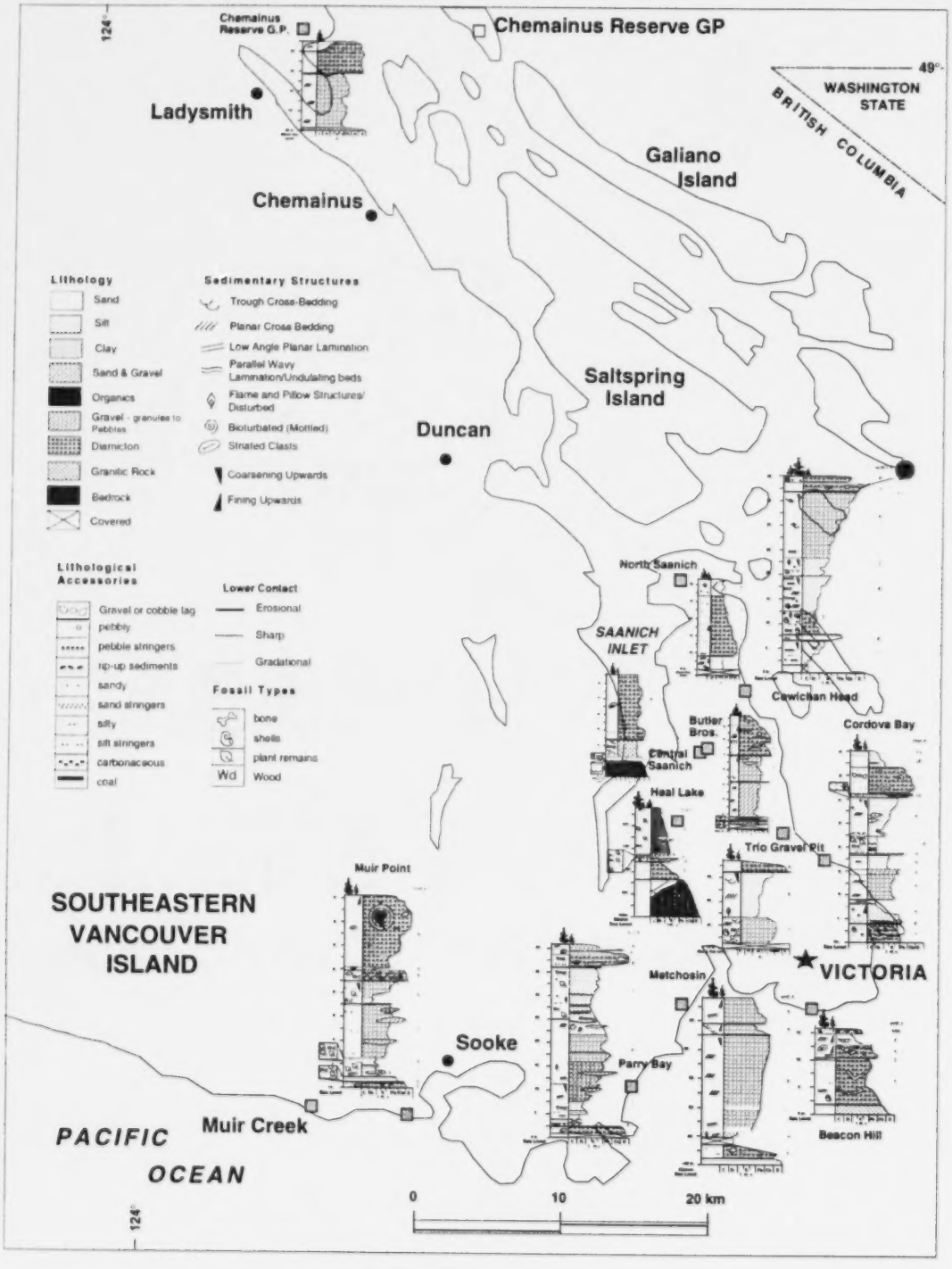


Figure 25: Corelation of Main Southeastern Vancouver Island Stratigraphic Sections

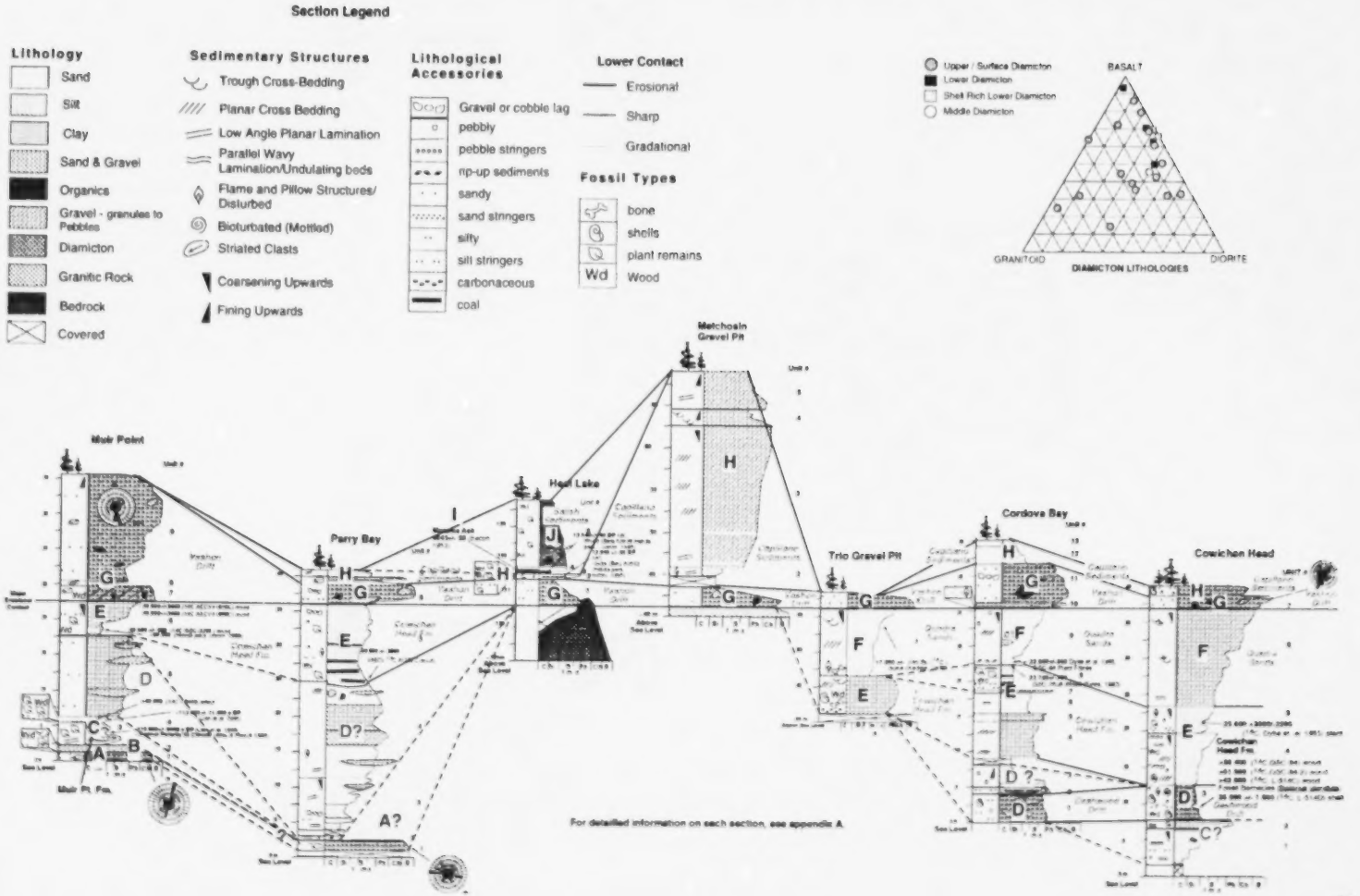
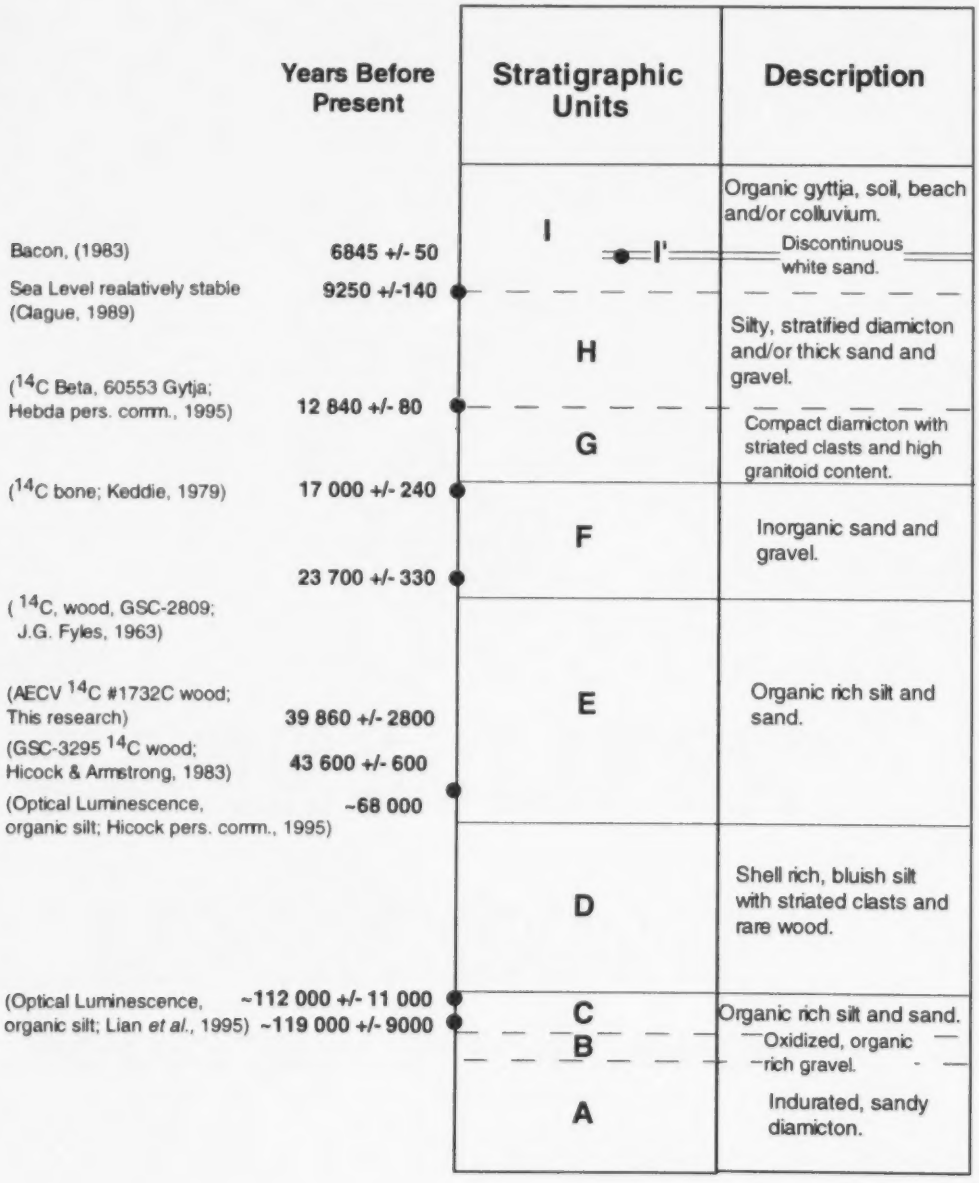


Figure 26: The Composite Stratigraphy of Southeastern Vancouver Island



The units identified in the seven most extensive sections on southeastern Vancouver Island (fig. 25; appendix A) are correlated as follows:

Unit A - Correlation: The first, and oldest unit identified on southeastern Vancouver Island appears to be a glacial deposit (refer to the following description and interpretation) found at the base of the Muir Point section (fig. 25, unit 1). It is identified by its stratigraphic position beneath two glacial, and two non-glacial units; the oldest of which is 119,000 +/- 9000 y BP (OL, Lian *et al.*, 1995). Unit A at Muir Point appears to correlate, lithologically, with unit 1 at Parry Bay, however, it can only be dated as greater than 39,860 y BP (AECV, ^{14}C, wood, #1732C) and only one glacial and one non-glacial deposit can be confirmed to overlie it. The glacial deposits at the base of the Cowichan Head (unit 3) and Cordova Bay (unit 1) (fig. 25) sections are lithologically similar to unit A at Muir Point, yet there is only one glacial and one non-glacial deposit above them. In addition, unit 3 at Cowichan Head is conformable with overlying non-glacial sediments dated at approximately 36,000 y BP (fig. 25) and unit 1 at Cordova Bay is lithologically and stratigraphically correlative with Cowichan Head.

Unit A - Description: (0-2 meters) Sandy Diamicton. This unit is a 0 to 3 meter thick greyish brown (no Munsell colour), moderately indurated diamicton (fig. 27) found at the base of the Muir Point and possibly the Parry Bay sections. It lies beneath all other units in the region, including an organic rich silt and sand dated at > 119 000 +/- 9000 y BP (Lian *et al.*, 1995). This unit is poorly stratified at its base, becoming massive in the upper portion of the section (fig. 28). The matrix is approximately 5-10 per cent silt and fine sand, 70-80 per cent medium sand and 10-15 per cent coarse sand and granules (hand textured) and constitutes approximately 65 per cent of the unit. Clasts comprise the remaining 35 per cent. The average clast size is 0.03 to 0.05 meters a-axis diameter to a maximum of 0.90 meters a-axis diameter. Many clasts are striated. Clast lithology consists of more than 50 per cent mafic volcanics, about 27 per cent dioritic rocks and 23 per cent sedimentary and miscellaneous rocks. Granitic clasts are rare, comprising no more than five per cent of the overall lithology (fig. 17). The fabric trends north-northeast to south-southwest with a 23° southwest plunge (appendix D, Muir Point Unit 1). The lower contact is covered.

Unit A - Interpretation: The moderate induration and basal stratification combined with striated clasts and relatively steep fabric (23°) indicate a probable flow till origin. Clast lithology shows local sources with a minor contributions from either coast mountain ice or re-entrenchment of previously deposited Cordilleran till.

Figure 27: Unit A, stratified to massive diamicton (Muir Point, unit 1).

Figure 28: Unit A, massive diamicton with well striated clasts (Muir Point, unit 1)

Unit B - Correlation: The second unit in this correlation is unique to Muir Point. It consists of an oxidized and cemented sand and gravel (refer to the following description and interpretation) which unconformably overlies unit A at Muir Point (figs. 25 and 29) and has not been found at Parry Bay, or any other section in the area. Its unconformable contact with unit C gives little indication of its age except greater than 119,000 +/- 9000 y BP (OL, Lian *et al.*, 1995).

Unit B - Description: (0-1m) Oxidized and Cemented Sand and Gravel. This material is represented by 0 to 1 meter of dark brown (7.5 YR 3/4) to iron oxidized red (no Munsell colour) sandy gravel (fig. 29), found at the base of the Muir Point section. It is highly indurated and cemented, with openwork lenses, and is moderately to well sorted. Unit B contains rare limonitic casts of wood and oxidized plant fragments. The matrix consists of medium to coarse sand with rare silt stringers. The clasts range in size from granules to large cobbles and are sub- to well rounded. The lower contact appears to be erosional (fig. 29).

Unit B - Interpretation: The sub- to well rounded granules to large cobbles in this unit appear to have a fluvial origin with a moderate to high flow regime. The trough and planar cross-bedding suggests shifting channels associated with a longitudinal bar and lag deposition, while the organic rich silt and limonitic wood casts appear to represent flood-overbank deposition. This unit is also found below the sample dated at 119,000 +/- 9000 y BP (Lian *et al.*, 1995), however, its erosional upper and lower contacts make correlation to either upper or lower units difficult. Previous work by Hicock and Armstrong, (1983) identified this unit (unit B), as belonging to the Interglacial Muir Point Formation.

Unit C - Correlation: Unit C appears only to exist at Muir Point (units 3 and 4) and is identified by its stratigraphic position beneath two glacial and two non-glacial deposits (fig. 25) (refer to the following description and interpretation), a high organic content (refer to the following description and interpretation) and an age of approximately 112,000 +/- 11,000 y BP to 119,000 +/- 9000 y BP (Lian *et al.*, 1995) (fig. 25). No other non-glacial units on southeastern Vancouver Island have been proven to be as old as unit C at Muir Point; stratigraphically, however, units 1 and 2 at Cowichan Head may be equivalent (fig. 25).

Unit C - Description: (~4.5 meters) Organic Rich Silt, Sand and Gravel. Unit C consists of sub-horizontally, interbedded silt and sand (fig. 30) with rare gravel lenses. This unit is well sorted and clasts within it are well to sub-rounded. Peat, plant detritus and

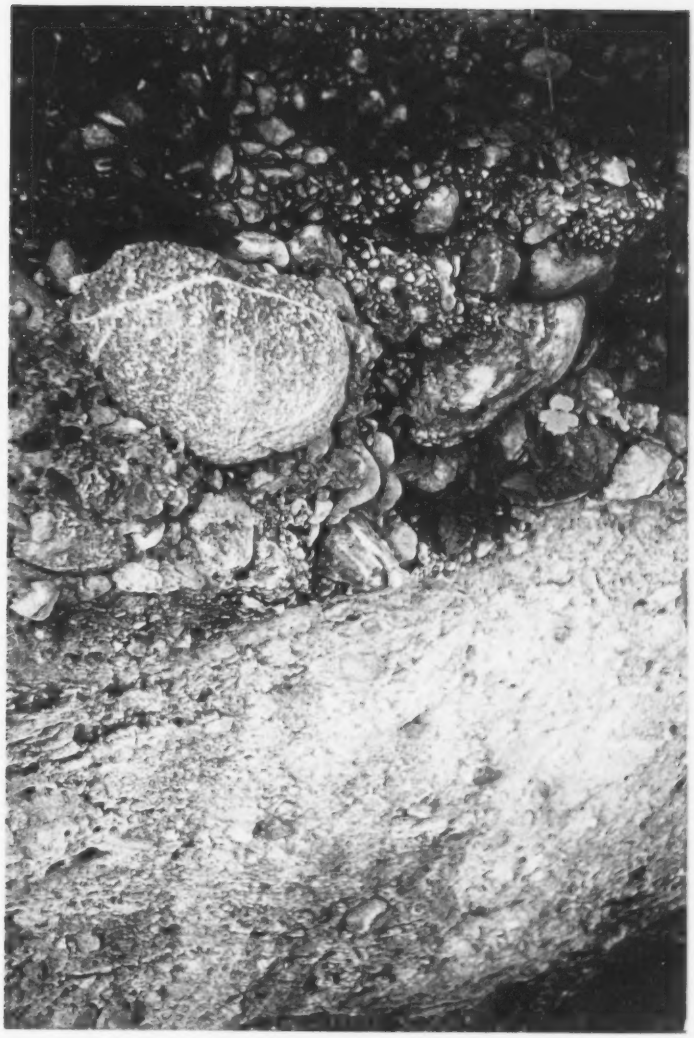


Figure 29: Unit B, oxidized and cemented sand and gravel, showing openwork lenses and erosional lower contact with unit A (Muir Point, unit 2).

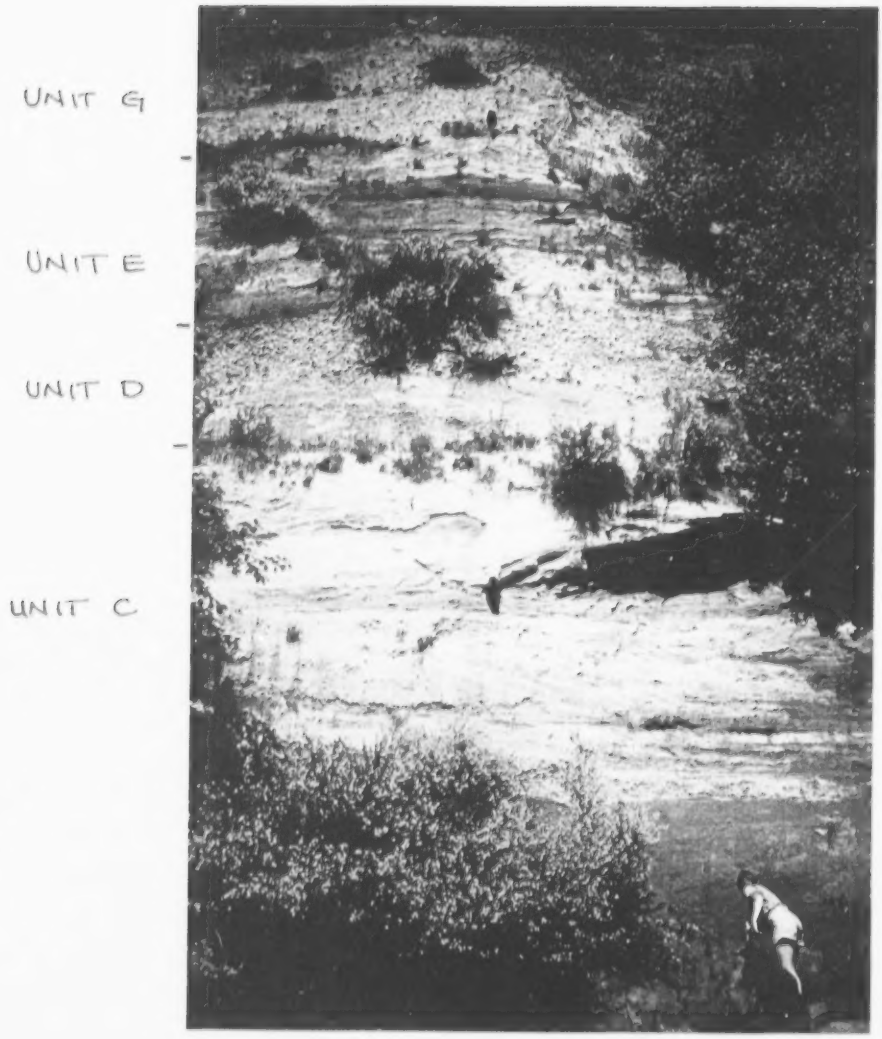


Figure 30: Unit C - Organic rich silt, sand and gravel overlain by unit D gravels (Muir Point, units 3,4 and 5).

in-tact plant remains, increase in concentration up section. Wood from this unit was dated at >40,000 years BP (^{14}C, I-8449, Hicock, 1993). Recent optical luminescence dating has suggested its deposition was between ~119,000 +/- 9000 y BP and ~112,000 +/- 11,000 y BP (Lian *et al.*, 1995). The lower contact is erosional.

Unit C - Interpretation: The organic rich silt and sand in the lower three meters of this unit (fig. 31) suggests either a low energy bog or flood plain environment. Sand and rare gravel lenses suggest gentle fluvial action punctuated by periodic channel shifts like those found in estuarine or flood plain environments. High organic content and fragmented plant remains indicate a detrital origin with either low decay rates or high organic influx rates. Rare marine dinoflagellate cysts (Alley and Hicock, 1986) show a minor marine influence or estuarine origin. The autochthonous peat found in the upper 1.5 meters of this unit implies a bog or marshland environment, probably deposited during a relatively productive and warm climatic phase. Increasing amounts of silt and sand at the eastern end of the unit suggests close proximity to a low energy, flood plain or marine environment. Palynological evidence and a normal magnetic polarity shows this unit to represent a true interglacial climate most likely deposited in the Brunhes normal epoch (Alley and Hicock, 1986).

Unit D - Correlation: Unit D is a glacial deposit (refer to the following descriptions and interpretations) known to be conformable with overlying, non-glacial sediments at Cowichan Head (units 4 and 5, fig. 25) dated at approximately 35,600 + 3000/-2200 y BP (GSC 200, plant, Dyck *et al.*, 1965). Given this stratigraphic location beneath one glacial and one non-glacial deposit unit D appears to be age bracketed between the interglacial sediments of unit C, which are approximately 112,000 +/- 11,000 y BP (Lian *et al.*, 1995) and the non-glacial sediments of unit E, which are no older than 68,000 y BP (optical luminescence (OL), Hicock, pers. comm., 1995) or conventionally dated, 43,600 +/- 600 y BP (^{14}C wood, GSC 3295, Alley and Hicock, 1986). Units 1 and 2 at Cordova Bay correlate lithologically with unit D at Cowichan Head (fig. 25) and chronostratigraphic correlations appear to exist between unit 5 at Muir Point and possibly, units 3 and 4 at Parry Bay (fig. 25).

Unit D - Description: (0-4 meters) Silt with Shells, Wood and Striated Clasts. Unit D is represented by two silt and shell-rich diamictons deposited at Cordova Bay (unit 1, refer to fig. 25) and Cowichan Head (unit 3), and is likely represented at Muir Point by a unit of interbedded coarse sandy gravel containing large lenses of coarse gravel and sandy diamicton (unit 5, fig. 32).

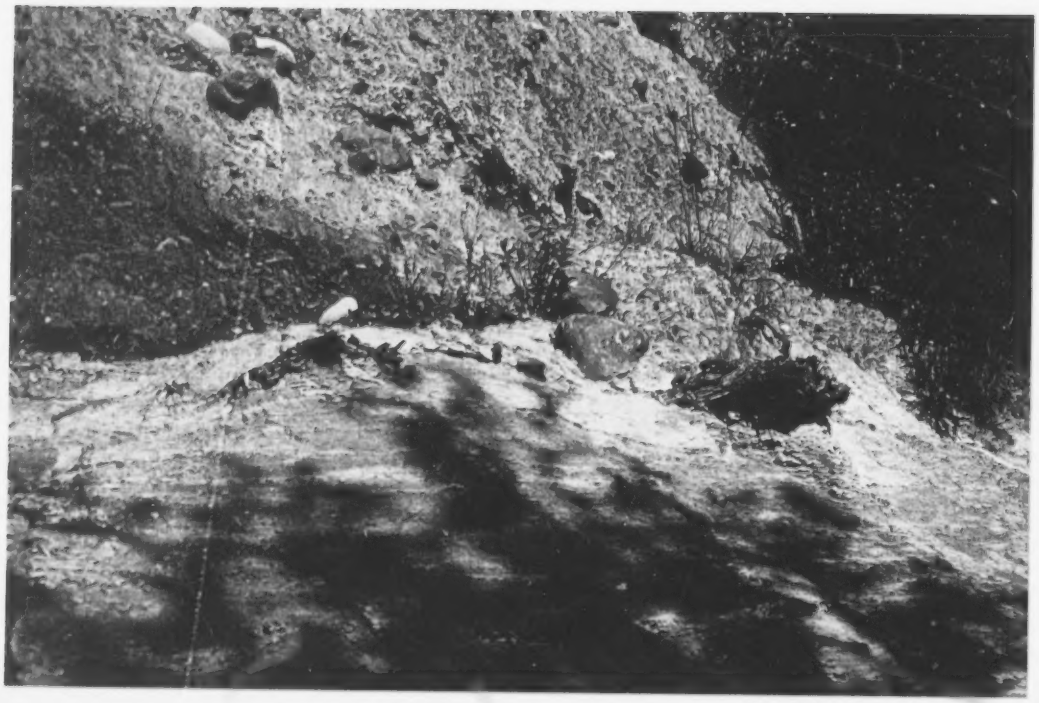


Figure 31: Unit C - Close-up of wood within the organic rich silt and sand (Muir Point, Unit 3)

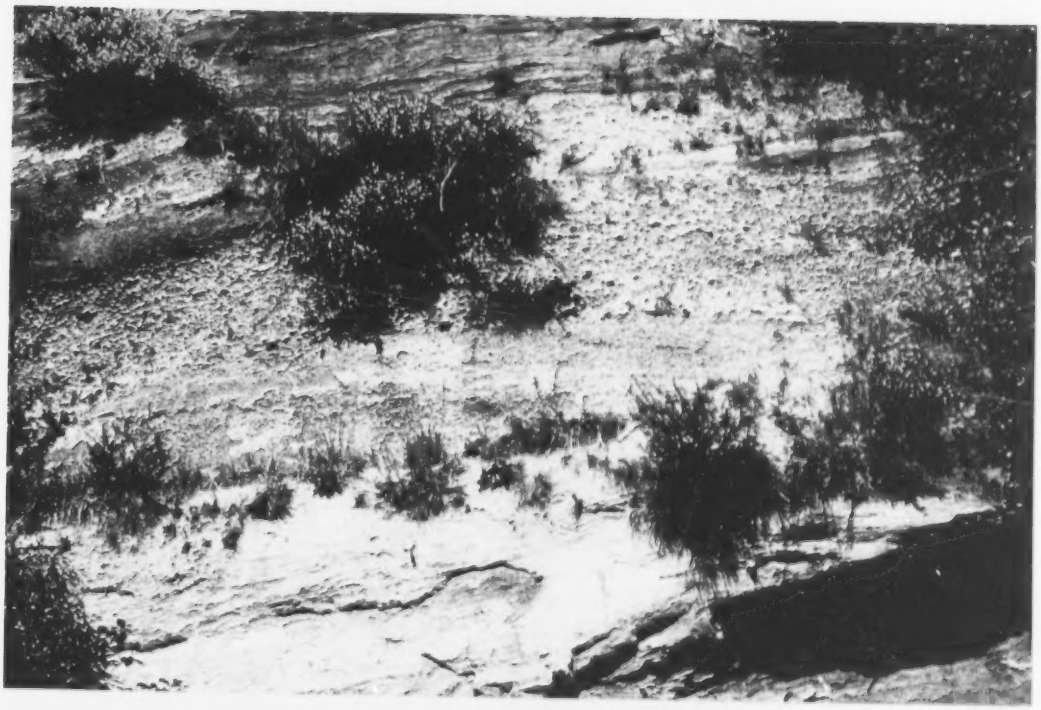


Figure 32: Possible unit D interbedded sand and gravel with lenses of coarse gravel and sandy diamicton (Muir Point, unit 5)

The deposits at Cordova Bay and Cowichan Head are identified by 0 to 4 meters of shell-rich bluish (7.5 YR 4/0), silty sand with mud and clay stringers and sediment-filled intersecting tubes (fig. 33). The deposits are 95 per cent matrix, with rare sub-rounded to sub-angular clasts ranging from 0.008 meters, to a maximum of 0.05 meters a-axis diameter . Many clasts are well striated (fig. 34) and appear to have deformed the silt beds beneath them (fig. 35). They are commonly covered with white circular marks (fig. 35). The matrix is approximately 37 per cent silt, 18 per cent clay and 46 per cent sand and shows poor bedding, distinguished by concentrations of manganese on the bedding plain surfaces (fig. 35). The lithology is similar at both Cowichan Head and Cordova Bay in that it contains 85-97 per cent mafic volcanic clasts, 26-27 per cent diorite and minor amounts of sedimentary rocks (fig. 9). The unit changes slightly from Cowichan Head to Cordova Bay where it shows a decreased number of sediment filled intersecting tubes and an increased concentration of (0.5-1 meter wide), undulated clay and poorly sorted, sub-rounded gravel lenses with shells (fig. 36). At Cordova Bay this unit is overlain by approximately one meter of poorly sorted, sub-angular to sub-rounded, coarse sand and gravel with minor silt and rare disintegrating granites. This gravel unit fines upward into 2 to 3 meters of horizontally bedded and slightly oxidized, coarse sand to blue-grey silt containing rare 0.03 meter, sub- to well rounded pebbles.

Unit D - Interpretation: At Cordova Bay and Cowichan Head the fine texture and poor bedding, combined with the barnacle marks (white circular marks) and shells imply a marine depositional environment. The intersecting, sediment filled tubes appear to be remnants of bioturbation. The striated cobbles and pebbles that appear to have disturbed the silt beds are dropstones from an overlying, or nearby, ice sheet or ice berg. Dates from the wood within this unit suggest that it is near, or beyond the range of radiocarbon dating (~35 000 y BP +/- 1600 years, L-514D wood; >42 000, L-514C, wood and >51 000 y BP GSC-94-2, wood; Fulton and Halstead, 1972; Olson and Broecker, 1959, respectively). Fossil barnacles (Balanus glandula) collected from the upper 2.5 meters of unit D indicate cool to temperate conditions (Alley, 1979). The horizontal bedded sand and gravel, composed primarily of Vancouver Island lithologies and rare Cordilleran ones, likely represents a beach or possibly a fluvial environment.

The deposits of unit D are age bracketed between non-glacial sediments as old as ~68,000 y BP, optical luminescence (OL, Hicock, pers. comm., 1995) or conventionally dated at 43,600 +/- 600 y BP, (^{14}C wood, GSC 3295, Alley and Hicock, 1986) and the Interglacial Muir Point Formation sediments (~112,000 +/- 11,000 y BP, OL, Lian *et al.*, 1995) and, using

Figure 33: Unit D - Sediment filled intersecting tubes within shell- rich silt (Cowichan Head, unit 3)

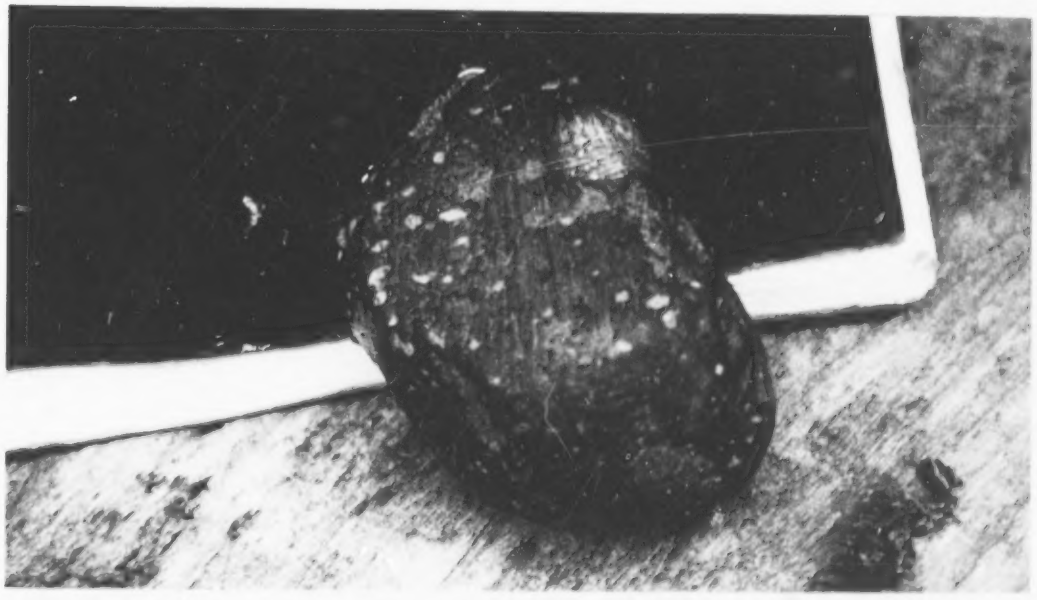


Figure 34: Striated clast with white circular marks in unit D (Cordova Bay, unit 1)

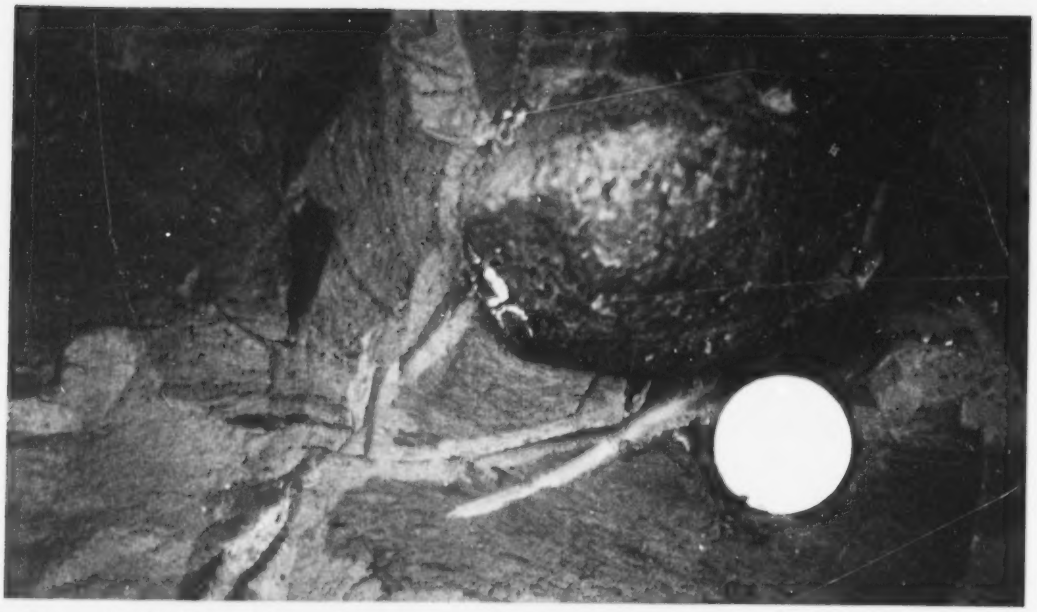


Figure 35: Unit D - Deformed manganese stained silt beds beneath a stone covered in white circular marks (Cowichan Head, unit 3). Quarter for scale.

Figure 36: Unit D -Undulating sand and gravel lenses with white marked clasts (Cordova Bay, unit 1).

the terminology of Fyles (1963), are termed Dashwood drift. (fig. 25). The sandy gravel with lenses that forms unit five at Muir Point (fig. 25) likely represents a low to moderate energy fluvial environment interrupted by large scale channel shifts and debris flows. Although unit 4 at Muir Point has previously been grouped with Sangamon, Muir Point Formation sediments (Hicock and Armstrong, 1983). The lack of pollen in the Muir Point sand and gravel (unit 5) (Hicock, 1980) may be the result of a cool climate or simply the function of a well washed depositional environment, however, new bracketing dates between material dated at ~112,000 +/- 11,000 y BP (OL, Lian *et al.*, 1995) and ~68,000 y BP, (OL, Hicock, pers. comm., 1995) suggests it correlation with glaciomarine sediments of a similar age at Cowichan Head and Cordova Bay probable.

Unit E - Correlation: Unit E is a subaqueous to subaerial organic rich sediment (refer to the descriptions and interpretations that follow), identified by its stratigraphic position above the glacial deposits of unit D and beneath the pro-glacial deposits of unit F and the glacial deposits and basal unconformity of unit G (fig. 25). It is an organic rich deposit best represented at Cowichan Head by units 4 and 5 (fig. 25), which form the type section for the Cowichan Head Formation of the Olympia non-glacial interval, introduced by Clague (1976) and defined by Armstrong and Clague (1977). Unit E is lithostratigraphically correlative across southeastern Vancouver Island and is age bracketed roughly between 68,000 y BP (OL, Hicock, pers. comm., 1995) or conventionally, 43,600 +/- 660 years BP (^{14}C, GSC 3295, Alley and Hicock, 1986) and 22,600 +/- 300 (GSC 84, plant fibers; Dyke *et al.*, 1965). It is exemplified by Unit 6 at Muir Point; unit 5 and possibly 4 at Parry Bay; Unit 1 at the Trio Gravel Pit; unit 4 through 8 at the Cordova Bay section and unit 4 and 5 at Cowichan Head (fig. 25).

Unit E - Description: (0-25 meters) Silt and Sand With Wood and Organic Rich Interbeds. Unit E is represented on southeastern Vancouver Island at Cordova Bay, Muir Point, Parry Bay and Cowichan Head. It is best represented at Cowichan Head by units 4 and 5 (fig. 25) which show an oxidized, coarsening upward sequence of planar cross-bedded sand (fig. 37) dipping from 2 to 25° up section and towards the south. Unit 4 at Cowichan Head exhibits minor, discontinuous interbeds of horizontally bedded gravel and apparently sand casts of marine worms (Armstrong and Clague, 1977). The upper unit at Cowichan Head (unit 5) contains organic rich silt with interbeds of sand and an oxidized, organic rich, silty-sand bed which extends across the section (fig. 37). The upper meter of this unit contains flame and pillow structures, while the lower contact is gradual.

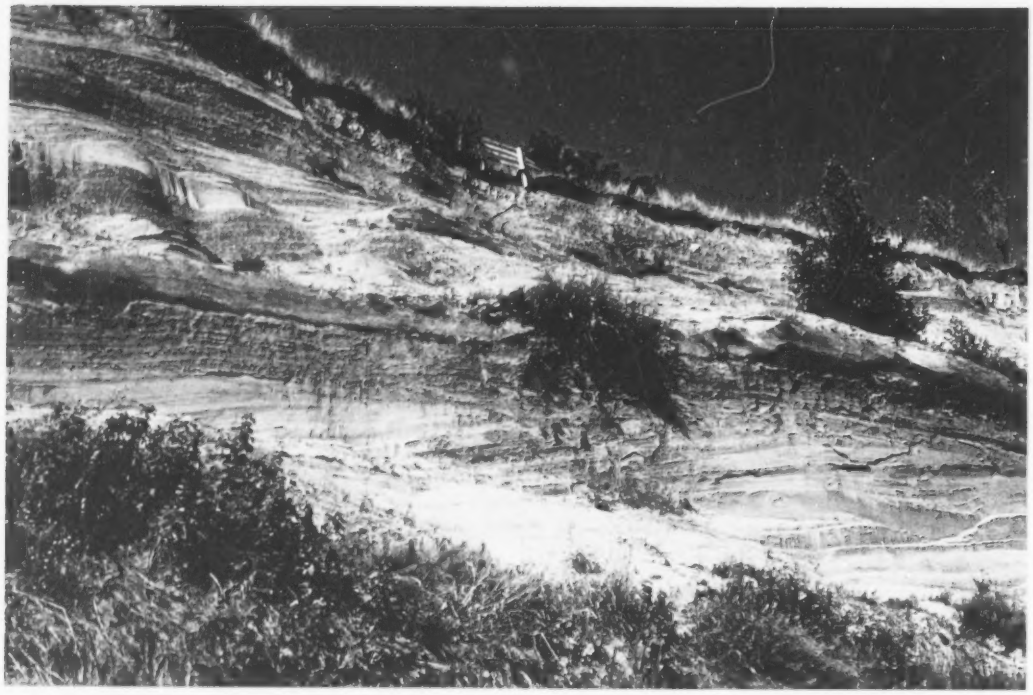


Figure 37: Unit E - Oxidized, planar cross-bedded sand, overlain by a thin oxidized, organic rich silt which extends across the section (Cowichan Head, units 4 and 5).

At Cordova Bay, about 5 kilometers southeast of Cowichan Head, a sequence of planar cross-bedded, oxidized, fine sand and gravel (units 4, 5, 6 and 7 fig. 25), similar to that of the Cowichan Head, is erosively overlain by poorly developed trough cross bedded moderately well sorted, sub- to well-rounded, sand and gravel (0.03 to 0.04 meter a-axis diameter). Overlying the gravel deposits are 1 to 2 meters of horizontally bedded fine sand and silt, erosively overlain by 0.01 meters of poorly sorted sand and gravel. Deposited on these gravels are horizontally bedded, very dark grey to black, organic rich silts (10 YR 3/1 to 10 YR 2/1 respectively), comparable to those of unit 5 at Cowichan Head but containing more organic material. The organics in this unit include wood, branches and plant remains, intact and broken, compressed, to almost lignitized (fig. 38 of displaced block of unit 8, Cordova Bay). The organics content decreases eastward and up section and is thickest at the centre of the Cordova Bay section (fig. 38).

At Muir Point (unit 6, fig. 25) unit E sediments are represented by 0 to 5 meters of organic rich, horizontally interbedded and well sorted silt, sand and gravel with organics that lessen up section (fig. 39). Clasts within this unit are well rounded and no greater than 0.02 to 0.03 meters a-axis diameter. A radiocarbon date of 43,600 +/- 660 years BP (^{14}C, GSC 3295, Alley and Hicock, 1986) was obtained on wood from near the base of this unit and recently an optical luminescence date of approximately 68,000 y BP was taken from sediment at the base of this unit (Hicock, pers. comm., 1995).

At Parry Bay (unit 5, fig. 25) unit E is represented by an organic rich, discontinuous sandy, silt with organic interbeds (fig. 40). The organic rich beds are most prevalent at the base of the unit and are generally very dark greyish brown (5Y 3/2). Wood from within these beds is compressed and mostly lacking bark. Other organic material from this unit tends to be broken and reworked. Wood from the unit's base was dated, for this research, at 39,860+/- 2800 years before present (^{14}C AECV 1732 C). Sand and silt beds from within this unit contain minor concentrations of coarse sand and small pebbles. Bedding is generally sub-horizontal and appears to dip towards the northeast. The lower contact is erosive as the entire unit cuts a 30 meter wide trough, 13 meters deep into unit D.

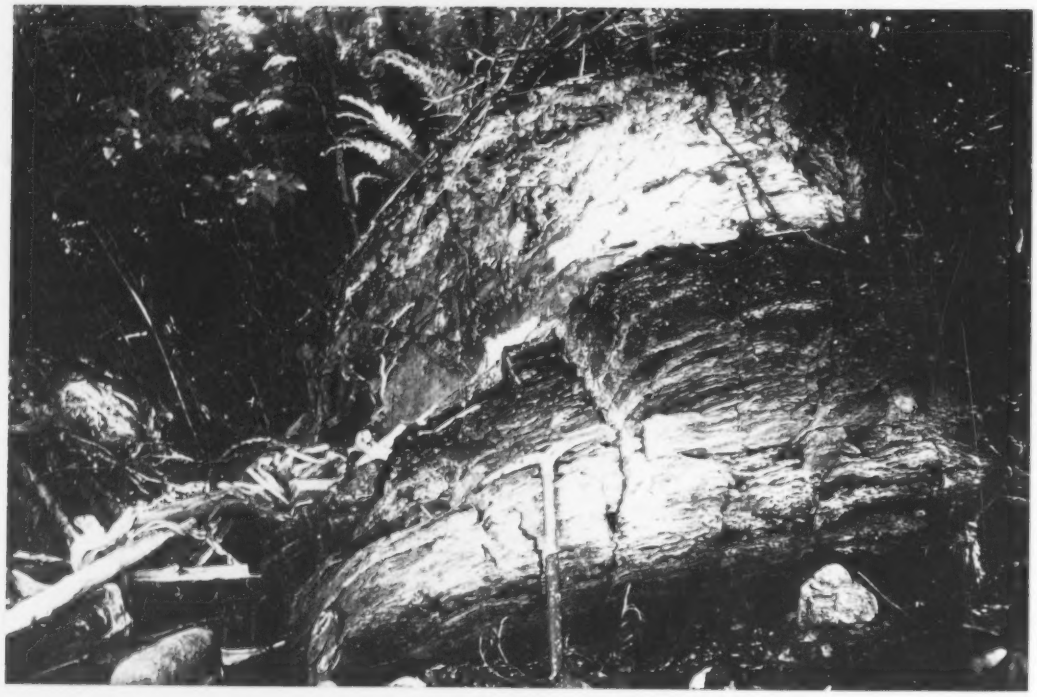


Figure 38: Unit E - Displaced block of organic rich silt (Cordova Bay, unit 8).

Figure 39: Unit E - Horizontally interbedded, organic rich silt, sand and gravel (Muir Point, unit 6).

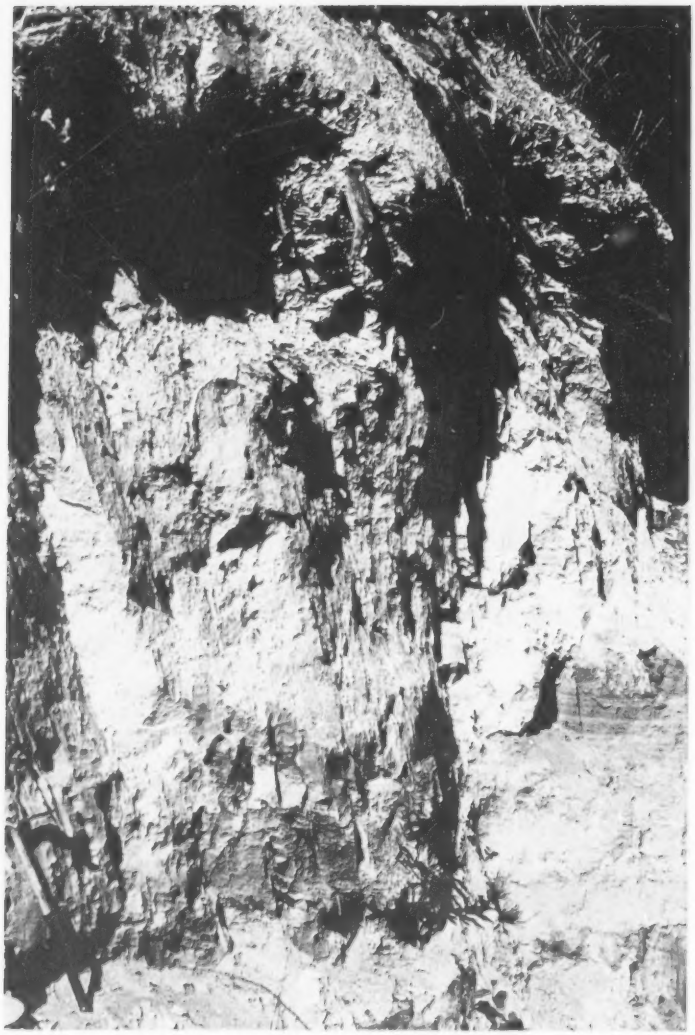


Figure 40: Unit E - Discontinuous and oxidized, sandy silt with organic interbeds (Parry Bay, unit 5). Pick at left of photo is approximately one meter long. Wood from the base of this unit taken from unoxidized silt and radiocarbon dated at 39,860 +/- 2800 y BP.

Unit E - Interpretation: At Cowichan Head unit E appears to be represented by prograding deltaic to estuarine deposits. Bedding directions indicate its source to be roughly from the north-northeast. The oxidized, organic rich, silty, sand bed which extends across the section about two meters from the top of the unit may represent an groundwater oxidized unit, however, the high organic content of this unit, including the plant fragments dated at 35,600 + 3000, -2200 y BP (GSC 200, plant, Dyck *et al.*, 1965) suggest it to be a paleosol (fig. 37) which may represent a depositional hiatus and possible climatic maximum. A similar concentration of detrital organics dated at 39,860 +/- 2800, can be found at Parry Bay (unit 5), suggesting that a climatic maximum may have occurred around 39,000 y BP.

At Cordova Bay unit E is represented by a fluvial, longitudinal bar or deltaic foreset deposit apparently from a higher flow regime than that of unit E at Cowichan Head. The horizontally bedded sand and gravel overlying the cross-bedded sand and gravel, beneath organic beds at Cordova Bay may be a beach or fluvial outwash deposit not identified at Cowichan Head. The organic rich unit at Cordova Bay (fig. 38) is a combination of detrital and in-situ organic material representing a low energy bog or fen. The broken fragments of wood and coal suggest a detrital influx of organics, and either reworked Cretaceous, Nanaimo sediments or charcoal.

At Muir Point, unit E is represented by horizontally bedded silt, sand and gravel possibly of a sub-aqueous to sub-aerial near shore lacustrine, marine, or fluvial origin. The abundant plant macro fossils and pollen, found in the lower two meters of this unit, show a climate cooler and moister than the modern one but apparently warmer than that represented by unit D of this sequence (Alley and Hicock, 1986).

At Parry Bay unit E deposits are found within an erosional trough formed within the sand and gravel of the lower unit. The fine sand, silt and detrital organics likely occur as a result of flood plain or flood-overbank deposition in a relatively warm climate. The conventional radiocarbon date taken from wood at the base of this unit shows it was deposited 39 860+/- 2800 years before present (AECV 1732 C) suggesting a relatively warm climate at this time. Decreasing organics up section show either an increase in sediment input over time, or a cooling climatic trend. A lack of dating control or paleoclimatic information for the oxidized silt, sand and gravel of units 2, 3 and 4 at Parry Bay (fig. 25) makes an accurate placement within the Quaternary history of southeastern Vancouver Island difficult.

Unit E - Summary: Unit E, identified by Clague (1976) and Armstrong and Clague (1977) as the Cowichan Head Formation, is well represented on southeastern Vancouver Island. The earliest known date for the deposition of these sediments in this area is approximately 68,000 y BP (OL, Hicock pers. comm., 1995), or conventionally at 43,600 +/- 600 y BP (^{14}C, wood, GSC 3295, Alley and Hicock, 1986) from Muir Point. The youngest date for the close of this depositional sequence on southeastern Vancouver Island comes from a 23,700 +/- 330 y BP radiocarbon date taken from wood at the base of unit 9 at Cordova Bay (Fyles, 1963, GSC - 2809 (fig. 25)). Sediments found within this age range, or possessing characteristics correlative to those of the Cowichan Head Formation are represented by (refer to fig. 25 for unit numbers):

Units 4 and 5 at Cowichan Head (the Cowichan Head Formation type section) represent deltaic to estuarine deposits dated at 35,600 + 3000, -2200 y BP (GSC 200 - plant fragments, Dyck *et al.* 1965).

Units 4,5,6,7 and 8 at Cordova Bay show a similar, yet higher flow regime, depositional sequence than at Cowichan Head and are overlain by beach and bog deposits not found at Cowichan Head. Cordova Bay provides the upper bracketing date for unit E with a date of 23,700 +/- 330 (^{14}C, GSC 2809, Fyles, 1963) from wood in overlying pro-glacial sediments.

Unit 6 at Muir Point represents a prograding lacustrine, or marine, to fluvial depositional environment, with a basal, bracketing date of approximately 68,000 y BP (OL, Hicock pers. comm., 1995; conventionally radiocarbon dated at 43 600 +/- 600 y BP; wood, GSC 3295, Alley and Hicock, 1986).

Unit 5 at Parry Bay appears to represent flood plain or flood-overbank deposition, dated by this study as being at least 39,860 +/-2800 years old (AECV, ^{14}C, #1732 C, wood).

The deltaic to estuarine transition at Cowichan Head, the deltaic to beach to bog deposits at Cordova Bay and the prograding lacustrine/marine to fluvial transition at Muir Point show relative sea level to have dropping during the deposition of unit E. At all of these locations, a steady decrease in organics up section indicates a general climatic deterioration (i.e. cooling) after 35,600 + 3000, -2200 y BP (GSC 200 - plant fragments, Dyck *et al.* 1965)

Unit F - Correlation: Unit F stratigraphically located directly beneath the glacial deposits and basal unconformity of unit G (fig. 25) and directly above the organic rich sediments of unit E (refer to the following descriptions and interpretations). It is characterized by a sandy/gravely texture and age bracketed between 22,600 +/- 300 (GSC 84, plant fibers; Dyke *et al.*, 1965) and 17,000 +/- 240 y BP (^{14}C, bone, Keddie 1979). Unit F is

represented at Cowichan Head by unit 6, at Cordova Bay by unit 9 and at the Trio Gravel pit by unit 2 (fig. 25).

Unit F - Description: (20-30 meters) Sand and Gravel. Located above the organic sand and gravel of unit E and directly below the unconformable till of unit G, is unit F a deposit characterized by 20-30 meters of coarsening upward sand and gravel. Unit F exhibits massive to horizontal bedding at its base which grades to planar, then trough cross-bedding, and finally horizontal bedding again at its top. Pebble concentrations (clasts averaging 0.01-0.015 meters a-axis diameter) occur at the base of the troughs (figs. 41) while flame and rip-up structures are found at the base of this unit (fig. 42). The massive sand, only found at the base of the Trio gravel pit, pinches out towards the west. It is overlain by horizontally bedded to laminated medium and fine sand which grades up to large scale, planar cross-bedding. At the Trio gravel pit the planar cross-beds dip roughly towards the south and southeast, while at the Butler Brother's and Chemainus Reserve gravel pits they dip roughly towards the east-southeast. In all of the sections the top 2-3 meters of unit F exhibit a coarsening upward sequence of trough cross-bedded sand and gravel which grades to sub-horizontal interbedded gravel and sand. The lower contacts of these sections tend to be abrupt and disturbed, gradational or covered.

Unit F was formally described and identified in the Fraser Lowland, as Quadra sands (Clague, 1976; 1977; Armstrong and Clague, 1977). Deposits that exhibit the characteristics of the Quadra sands are found at Cowichan Head (unit 6), the Trio gravel pit (unit 2), Cordova Bay (unit 9) (fig. 25), the Butler Brother's gravel pit (units 3 and 4, appendix A), the Central Saanich gravel pit (unit 3, appendix A), the North Saanich gravel pit (unit 1, appendix A) and the Chemainus Reserve gravel pit (unit 1, appendix A).

Figure 41: Unit F - Trough cross-bedded sand and gravel with pebble concentrations at the base of troughs (Trio Gravel Pit, unit 2)

Figure 42: Unit F - Dark coloured, planar cross-bedded sand, overlain and ripped up by light coloured, disturbed sand (Cordova Bay, unit 9). Rock hammer head at the base of the photo is approximately 15 centimeters long.

Unit F - Interpretation: Unit F is age bracketed on southeastern Vancouver Island, between a basal date of 23,700 +/- 330 (^{14}C, wood, GSC - 2809, Fyles, 1963) and 17,000 +/- 240 y BP (^{14}C, bone, Keddie 1979) as found from a radiocarbon date on bone from near the top of the unit (fig. 25). The massive sand, flame structures and rip-up beds at the base of unit F are indicative of rapid deposition and high bedloads, typical of a debris flow environment. The overlying horizontal to planar-, to trough cross-bedded sand, found moving up unit F, may represent a bottom-set to top-set deltaic sediments originating from the Cowichan Valley and northern Georgia Strait, as measured from planar cross-bed trends. Pollen assemblages show this unit to have been deposited in a climate cooler than today (Fyles, 1963; Clague, 1977). It is likely that unit F was formed by the coalescence of pro-glacial outwash from Vancouver Island and Cordilleran ice. The light coloured, disturbed sand found near the base of unit F at Cordova Bay, which contains rip-up sediments of the darker sands from below (fig. 42) may also represent the contact between the mafic Cowichan Valley (Vancouver Island) glaciofluvial sands, overlain and disturbed by felsic Cordilleran outwash. The coarsening upward nature of this deposit suggests a prograding environment.

Unit G - Correlation: Unit G is a glacial till [See morainal materials Mb, in the surficial geology section for a detailed description], found at or near the surface and dated between 17,000 +/- 240 y BP (^{14}C, bone, Keddie 1979) and 12,840 +/- 80 y BP (Gy^{t}tja, Beta 60553; Hebda, pers. comm., 1995). It is one of the most widely distributed units in the area and its basal unconformity (fig. 43) provides an allostratigraphic marker below which sediments on southeastern Vancouver Island are approximately 17,000 y BP or older. Unit G is represented on southeastern Vancouver Island (fig. 25) by units 7, 8 and 9 at Muir Point; unit 6 at Parry Bay; unit 1 at Heal Lake; unit 1 at the Metchosin gravel pit; unit 3 at the Trio gravel pit; units 10 and 11 at Cordova Bay; unit 7 at Cowichan Head; unit 2 at the Chemainus Reserve gravel pit and as surface deposits shown in figure 13.

Unit G - Description and Interpretation: (3-35 meters) Diamicton at or Near the Surface. Unit G is a silty to sandy diamicton identified by its stratigraphic position at, or near the modern land surface. Unit G is identified by its compact nature, numerous striated clasts and high concentration of Cordilleran lithologies [See morainal materials Mb, in the surficial geology section for a detailed description]. This unit is distributed throughout southeastern Vancouver Island, the Gulf Islands (fig. 13) and most of western British Columbia, and was formally identified by Willis (1898) as Vashon till. The surface and near surface deposits of unit G have a wider distribution of lithologies than unit A or D (fig. 17) reflecting a mixture of Vancouver Island and Coast Mountain lithologies.

Figure 43: Basal unconformity between units F and unit G, at Cordova Bay (units 9,10 and 11) (left photo) and at the North Saanich Gravel (right photo). Both picks are approximately one meter long.

Unit H - Correlation: Unit H is identified by its stratigraphic position directly above unit G, its subaqueous to sub-aerial facies change (refer to the descriptions and interpretations that follow) and its age between 12,840 +/- 80 y BP (Gyttja, Beta 60553; Hebda, pers. comm., 1995) and approximately 9,250 +/- 140 (Clague, 1989). Unit H is represented in the field area by units 7 and 8 at Parry Bay; unit 3 at Heal Lake; units 2 through 5 at the Metchosin gravel pit; units 12 and 13 at Cordova Bay; unit 8 at Cowichan Head (fig. 25) and as $Mb across the Saanich Peninsula and Victoria areas (fig. 13).

Unit H - Description: (1-48 meters) Silty Diamicton to Thick Sand and Gravel. Unit H ranges from sand, to gravel, to a silty diamicton. It varies across southeastern Vancouver Island but is identified by its stratigraphic position directly above the youngest till (unit G) and its sub-aqueous to sub-aerial facies transition.

Unit H at Cowichan Head (unit 8, fig. 25), and throughout the low lying surface areas of Victoria and the Saanich Peninsula is composed of discontinuous, brown clay with numerous pebble inclusions, locally termed Victoria clays. The term 'Victoria clay' has not been used in this work but is replaced with the mapping terms $dMb to $W^{G}b$ which represents a silty, morainal blanket or glaciomarine blanket respectively. This unit is dark greyish brown (2.5Y 4/2) and has an average matrix composition of 74 per cent fine sand, 16 per cent silt and 11 per cent clay (Sedigraph textured). It becomes both finer in texture and bluer in colour at depth (Thurber Engineering pers. comm., 1992). It contains from 5 to 30 per cent clasts ranging from 0.01 meter to 1 meter a-axis diameter and averaging 0.01 meters in diameter. Clasts are rounded to sub-rounded and are composed of quartzite, sandstone, siltstone, basalt and disintegrating granite. Unit H contains rare shell fragments throughout. The lower contact is generally gradual to abrupt.

At Metchosin, unit H, directly overlying the youngest till (unit G), is represented by 0 to 0.07 meters of olive brown (2.5Y 4/4) fine silt and clay (clay 10-15 per cent; silt 90-95 per cent; hand textured), laminated to planar cross bedded up section. The fine laminations and low angle planar cross-bedded silt and sand dip towards the east (09° towards 076°) and are overlain by 2.5 to 17.0 meters of large scale, planar cross-bedded, gravel and cobbly gravel with apparent dips of up to 25° towards the south-southwest (unit 3, figs. 44, 45). The gravel is interbedded with sub-horizontal medium to coarse sand which decreases in bed thickness, from approximately 0.35 meters at the base to a maximum of 0.10 meters up section. The gravel beds increase in frequency and thickness towards the top, (i.e. their maximum

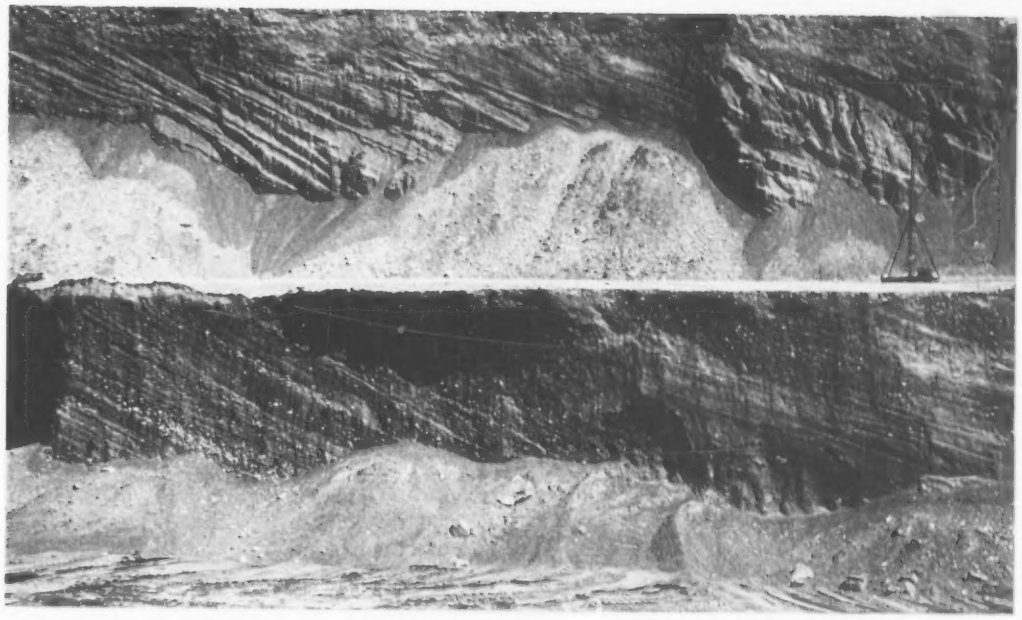


Figure 44: Unit H - Planar cross-bedded gravel near the base of the unit (Metchosin gravel pit, unit 3, facing 016°). The scale is a light standard approximately eight meters high.

Figure 45: Unit H - A view towards 100° southeast at the Metchosin gravel pit (unit 3). The scale is two meters high.

thickness at the base is ~0.30 meters while at the top of the unit it is up to 2.0 meters in thickness). The bedding becomes finer, more horizontal to lenticular when viewed towards the south at the same elevation(fig. 45). The coarsest gravel is openwork and manganese stained. Clasts are well rounded and are comprised of a wide variety of lithologies including basalt, gneiss, quartzite, conglomerate and abundant granitoid rocks (appendix B). The lower contact is gradational and generally conformable.

Unit H at Heal Lake is represented by fine to coarse sand with organic partings, deposited directly above the till of unit G (fig. 46). The deposit at Heal Lake is characterized by ~0.18 to 0.05 meters of well sorted, fine to coarse textured, sand. It is a very dark grey (5Y 3/1) sand with minor organic partings in the basin and increasing organics towards the unit's top. The organic material is partly broken but to a great extent retains its original form and texture. It was radiocarbon dated at 12,840 +/- 80 y BP (Gyttja, Beta 60553; Hebda, pers. comm., 1995). The bedding is poor to sub-horizontal and the unit contains rare lenses of sub-rounded cobbles. The cobbles range in size from 0.02 to 0.12 meters a-axis diameter. The lower contact is sharp and erosional. This unit is overlain by 0.06 to 0.09 meters of dark brown (7.5 YR 3/2) silty organic gyttja (unit 3) full of broken twigs, bark, pine needles and lodge pole pine cones (Hebda pers. comm., 1992). A lateral continuation of this unit, 30 meters towards the basin shows a decrease in organics and an increase in clay, silt and sand.

Unit H - Interpretation: The silty diamicton of unit H at Cowichan Head appears to have a glaciomarine origin and is probably the result of sub-marine deposition of silt, clay and dropstones on a isostatically depressed landscape.

Unit H at Metchosin represents a low flow regime bottomset, to higher flow regime foreset to topset, deltaic environment. This deposit appears to have had an easterly source, likely the Goldstream River, however, planar cross bedding shows that later deposition must have been dominated by fluvial activity from the northeast. The steeply dipping well graded sand and gravel of unit 3 at the Metchosin gravel pit represents a prograding subaqueous deltaic foreset facies, deposited in front of the down-wasting Cowichan Valley ice mass as it receded into the Saanich Inlet and Goldstream Valley. The two meters of fining upward gradational to erosive, trough cross-bedded sand and gravel found at the top of this section (fig. 47), would likely represent braided scour and fill bedding associated with a top-set deltaic environment. The prograding nature of this unit is likely the result of

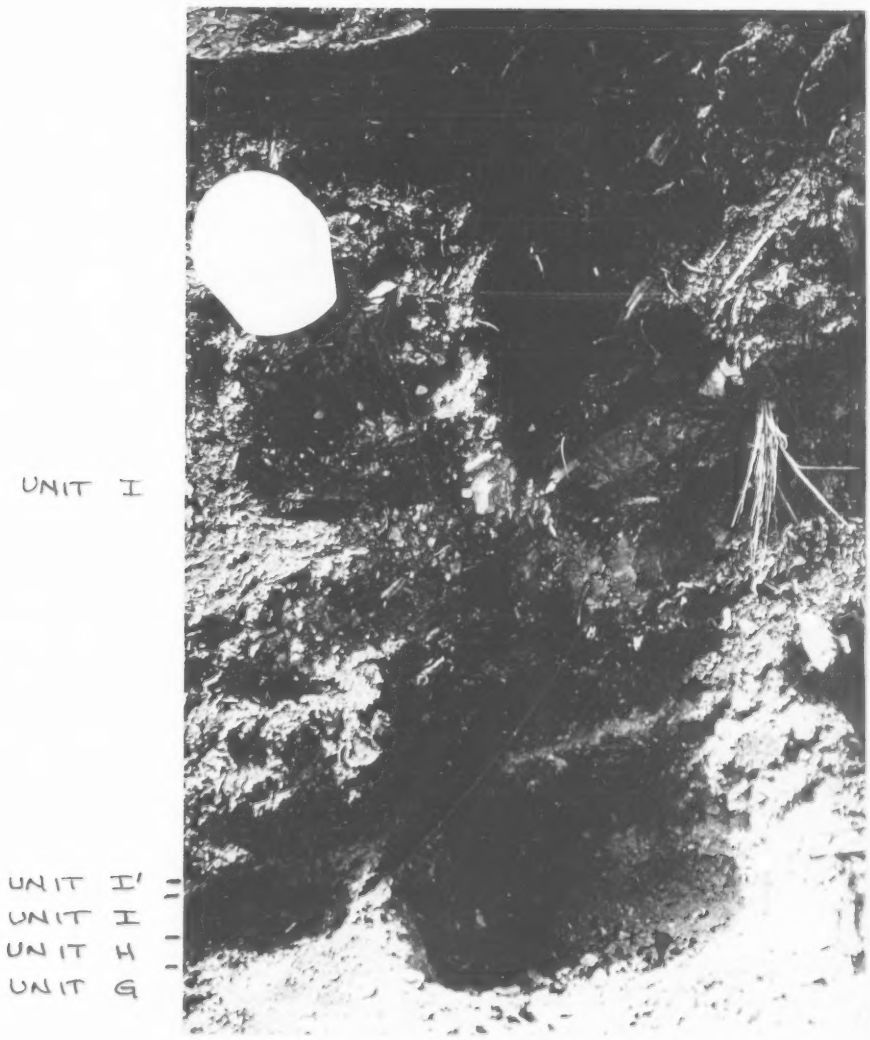


Figure 46: Units H, I and I' at Heal Lake.(Heal Lake, units 1 to 5). Hard-hat for scale.
Unit H - Coarse sand with organic partings deposited above the diamicton of unit G.
Unit I - A reddish brown, organic gyttja, containing logs and branches.
Unit I' - A discontinuous light grey, fine sand.

Figure 47: Unit H - Horizontal and trough cross-bedded sand and gravel at the top of the Metchosin gravel pit (units 4 and 5).

a dropping sea level rather than an advancing ice front, due to the post-glacial age of the deposit, however, a stagnant ice front or a nearby advancing ice front cannot be completely ruled out.

Unit H at Heal Lake has its origins in a low energy lacustrine environment with rare flooding events or channel shifts. The increasing organic content up section and its mostly intact nature is a result of an in-situ depositional environment and an increasingly productive climatic. The clay, silt and sand found towards the bottom of the basin indicates a low energy lacustrine environment.

Unit H - Summary: Unit H represents post-glacial deposits from various environments. One of these includes a coastal lowland environment, dominated by silty and partly stratified, glaciomarine tills such as found at surface across the Saanich Peninsula and Victoria areas (Change map symbol from $Mb to W^G) Parry Bay, (units 7 and 8, fig. 48), Beacon Hill, units (1 and 2), the clay-rich diamictons of Cowichan Head (unit 8), the North Saanich gravel pit (unit 4), the Pat Bay surface diamicton (unit 1) and the Foul Bay road surface diamicton (unit 1).

Post-glacial raised glaciofluvial sands and gravels found at the Metchosin/Colwood delta, the Muir/Kirby Creek delta and the Cowichan Valley delta, were deposited when southeastern Vancouver Island was isostatically depressed and sea level was approximately 85 meters above present, as measured from the top of the Metchosin glaciofluvial delta. Synchronous to the formation of these units was the deposition of post-glacial organic sediments, such as found at Heal Lake and Rithet's Bog, near Victoria. An erosional surface caused by post-glacial sea level change is seen in the form of coastal wave cut platforms such as those of the Gulf Islands and the Ladysmith areas. These wave cut platforms are seen at approximately 4 meters above sea level (i.e. at Bennett Bay on Mayne Island, Rutter pers. comm., 1993) and were probably formed during a minor sea level rise and coastal submergence around 11,500 y BP (Mathews, 1970; Clague, 1975).

Unit H materials deposited under post-glacial conditions have formally been termed, 'Capilano Sediments' (Armstrong and Brown, 1953; Fyles, 1963). They are dated as no older than the retreat of the last glaciation on southeastern Vancouver Island (~12,840 +/- 80 y BP, ^{14}C Gyttja , Beta 60553, Hebda pers. comm., 1995) and no younger than the cessation of isostatic rebound (approximately 11,500 y BP, Clague, 1975).

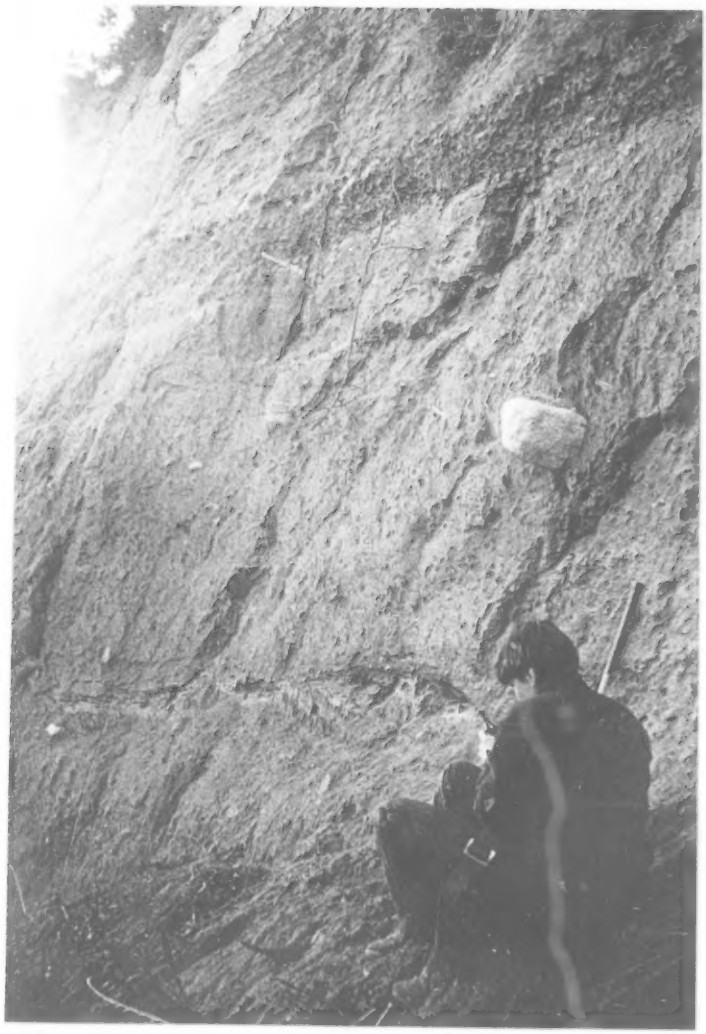


Figure 48: Unit H - Partly stratified diamicton at Parry Bay (units 7 and 8).

Unit I - Correlation: Unit I is identified by its association with modern depositional environments (refer to the descriptions and interpretations that follow) and its age between 9250 +/- 140 y BP (Clague, 1989) and present. Unit I is best represented by unit 5 at Heal Lake, however, it is represented by modern soil formation, and active depositional environments throughout the area.

Unit I - Description: (0-2.5 meters) Modern Organic Gyttja, Soil, Beach or Colluvium. Unit I deposits are identified by their bounding surface unconformity, age and stratigraphic position above all other units. Unit I includes modern soils (fig. 49), beach deposits, upland colluvium and lacustrine or bog sediments. Heal Lake, a recently drained and dredged upland lake, contains glacial and post-glacial deposits from units G through I (fig. 46). Its representation of unit I is the most extensive presently exposed on southeastern Vancouver Island. It is comprised of approximately 2.50 meters of dark reddish brown (5.5 YR 2.5/2) peat and gyttja, containing abundant tree branches and trunks, up to 0.20 meters in diameter, and with much of their original bark still intact. This unit also contains 0.05 meter thick, trough shaped, sand and gravel lenses, some up to 1 meter across, with well sorted and rounded sand, gravel and rare angular clasts of gneissic rock as large as 0.05 meters a-axis diameter, particularly evident just above unit I. The unit dips down slope in the direction of the basin bottom and has a sharp lower contact.

Unit I - Interpretation: Unit 5 at Heal Lake is a deposit of detrital and in-situ organics formed in a low energy, sub-aqueous environment. The gravel lenses suggest a fluvial influence with rare flooding events. Local angular clasts and large tree trunks suggest an accumulation basin where organic detritus fell between horizons of low energy fluvial and lacustrine sediments. Rare angular clasts of gneissic rock, similar to that of the surrounding bedrock, appear to have no colluvial source (i.e. steep rock face), yet were likely derived from freeze-thaw activity associated with a cold climatic phase after the deposition of unit I', approximately 6845 years ago. The tree remains present within unit I at Heal Lake include Douglas Fir, Lodge Pole Pine and Western Red Cedars (Richard Hebda, per. comm., August 12, 1992) and are very similar to those of the present vegetation (refer to Physiography).

Unit I' - Correlation: Unit I is identified by its light grey colour, well sorted nature (refer to the descriptions and interpretations that follow) and its age of 6845 +/- 50 y BP (Bacon, 1983). Unit I' was only found at Heal Lake.

Figure 49: Unit I - Modern soil development within unit 5, at the top of the Metchosin gravel pit.

Unit I ' - Description: (0.01 meters) Discontinuous, light grey sand. Unit I consists of light grey (10 YR 7/1), medium to fine grained, well sorted sand. It has a gritty hand texture and a high contrasting colour compared to the surrounding sources. It is discontinuously dispersed and poorly horizontally bedded. The lower contact is abrupt.

Unit I '- Interpretation: The highly contrasting colour (fig. 46) and well sorted nature, combined with a lack of local source suggests that unit I is likely an ash. The only ash known to have reached this area of Vancouver Island is the Mazama ash (Clague et al., 1995) from the 6845 +/- 50 y BP (Bacon, 1983) eruption of Mount Mazama. The identification and age of unit I was confirmed by R. Hebda (pers. comm., 1995).

Summary:

The ten stratigraphic units identified on southeastern Vancouver Island, from oldest (A) to youngest (I') are summarized as follows (refer to figure 26):

Unit A: The oldest unit is a sandy till identifiable by its indurated nature, its highly mafic lithology and its stratigraphic position beneath two glacial, and two non-glacial units; the oldest of which is 119,000 +/- 9000 y BP (OL, Lian *et al.*, 1995).

Unit B: Unit B is an oxidized gravel, identified by its oxidized and cemented nature, its age of greater than 119,000 +/- 9000 y BP (OL, Lian *et al.*, 1995) and its stratigraphic position unconformably overlying the oldest glacial deposits of unit A and underlying the organic rich sediments of unit C.

Unit C: Unit C is an organic rich silt and sand, notable for its stratigraphic position beneath two glacial and one non-glacial deposit (tig. 25), a high organic content and age of approximately 112,000 +/- 11,000 y BP to 119,000 +/- 9000 y BP (Lian *et al.*, 1995) (fig. 25).

Unit D: This glacial deposit is identifiable by its stratigraphic position beneath non-glacial unit E sediments and its bracketing dates of approximately 112,000 +/- 11,000 (Lian *et al.*, 1995) and 68,000 y BP (Hicock pers. comm., 1995).

Unit E: Unit E consists of subaqueous to subaerially deposited, organic rich sediments, most notable for their age of between 68,000 y BP (Hicock pers. comm., 1995) and 23,700 +/- 330 y BP (GSC-2809, ^{14}C, wood; J.G. Fyles, 1963), and their stratigraphic position above the glacial deposits of unit D and beneath the inorganic sands and gravels of unit F,.

Unit F: Unit F consists of sand and gravel, identifiable by its inorganic coarsening upward nature, its stratigraphic position directly above the organic rich sediments of unit E and beneath an extensive unconformity at the base of unit G, and its age of between 23,700 +/- 330 y BP (GSC-2809, ^{14}C, wood; J.G. Fyles, 1963) and 17,000 +/- 240 y BP (^{14}C, bone; Keddie, 1979).

Unit G: Unit G is represented by a till, at or near the surface, identifiable by its compact nature, numerous striated clasts, commonly high granitoid content and stratigraphic position above a basal unconformity that forms the allostratigraphic boundary below which sediments are 17,000 +/- 240 y BP (^{14}C, bone; Keddie, 1979) or older. Unit G has an upper age bracket of approximately 12,840 +/-80 y BP (^{14}C beta, 60553 Gyttja, Hebda pers. comm., 1995).

Unit H: Unit H is identified by its stratigraphic position directly above unit G, its subaqueous to sub-aerial facies change and its age between 12,840 +/- 80 y BP (Gyttja, Beta 60553; Hebda, pers. comm., 1995) and approximately 9,250 +/- 140 (Clague, 1989).

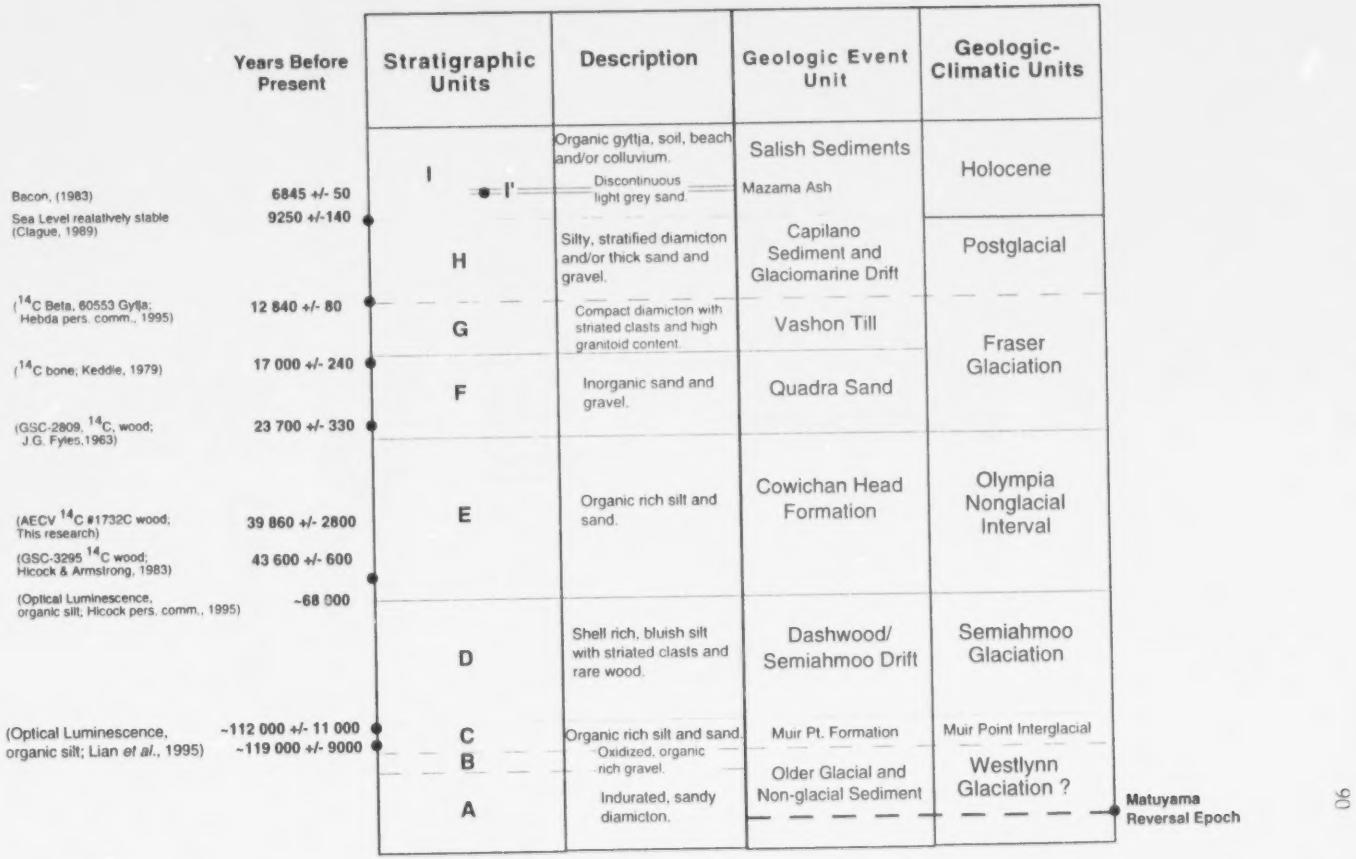
Unit I: Unit I is represented by the modern organic gyttja, soil, beach or colluvium deposits, and is identified by its bounding surface unconformity, stratigraphic position above all other units and its age between 9250 +/- 140 y BP (Clague, 1989) and present.

Unit I': Unit I' is identified by its light grey colour, well sorted nature, and stratigraphic position within, yet near the base of, unit I. This unit has been identified by Dr. R. Hebda as Mazama ash (Hebda pers. comm. 1995) and dated around 6845 +/- 50 (Bacon, 1983).

Quaternary History

The Quaternary history of southeastern Vancouver Island is dominated by the interactive growth and decay of the Vancouver Island and Cordilleran ice sheets which resulted in the deposition of thick sequences of both glacial and interglacial sediments. Excluding the Late Wisconsinan sediments of the last glaciation (Vashon till), and younger, most Quaternary deposits in the area have been eroded by subsequent glacial events. In some protected valleys and coastal lowlands, however, extensive stratigraphic sequences have been preserved. These sequences reveal a history of three glacial and three non-glacial periods(fig. 50).

Figure 50: The Composite Stratigraphy of Southeastern Vancouver Island. Dates derived from this and previous research.



The Quaternary history of southeastern Vancouver Island is arranged firstly by time stratigraphic unit and secondly by the geologic event unit, followed by the bracketed dates from this and previous research.

Pre-Sangamon or Earlier - Older Glacial Sediments (>119,000 y BP) - Westlynn Glaciation?

Before 119,000 y BP, a glaciation occurred which deposited the flow and basal till of unit A, at Muir Point. The ice mass that deposited this till appears to have originated on Vancouver Island, however, lithologic evidence shows minor interaction with Cordilleran ice. The lesser concentrations of Cordilleran lithologies in pre-Wisconsinan till, compared to that of Late Wisconsinan till, indicates a less extensive pre-Wisconsinan glaciation. This may be the result of a shorter glacial period or a drier, less productive climate, than that of the Late Wisconsinan.

Sangamon or Earlier - Muir Point Formation or Older, Non-glacial Sediments (>119,000 y BP) - Muir Point Interglacial or Older.

Prior to 119,000, yet after the earliest recorded glaciation on southeastern Vancouver Island, a period of non-glacial fluvial activity and organic productivity occurred resulting in the deposition of unit B. The deposits from this period may be related to the climatic warming of the Sangamon Interglacial, or an earlier non-glacial period.

Sangamon - Muir Point Formation, Interglacial Sediments (~119,000 to ~112,000 y BP) - Muir Point Interglacial

By 119,000 y BP Muir Point, and likely most of southeastern Vancouver Island, was undergoing both climatic warming and coastal emergence. The fluvial sand and gravel of unit B was overlain by estuarine silt, sand and detrital organics of unit C. By 112,000 y BP major fluvial channels had shifted away from the Muir Point area leaving wetlands, peat bogs and trees. The region was thriving in a climate similar to that found on southeastern Vancouver Island today.

Early Wisconsinan - Dashwood Glacial Drift (~112,000 to 68,000 y BP) - Semiahmoo Glaciation

The Early Wisconsinan on southeastern Vancouver Island is marked by the deposits of unit D, which represent a period of climatic deterioration. Marine organisms, adapted to cold water (Alley, 1979), dominated the near-shore environments of the southern island, while glacial detritus dropped from floating Vancouver Island ice above them. Minor contributions of Cordilleran material within the marine sediments suggest that Cordilleran ice likely reached the Strait of Georgia, however, did not reach as far south as the study area. Lowland regions of southeastern Vancouver Island, such as Muir Point, appear to have experienced increased fluvial and debris flow activity suggestive of increased precipitation rates.

Middle Wisconsin - Cowichan Head Formation, Non-glacial Sediments (68,000 to 23,700 y BP) - Olympia Non-glacial Interval

By approximately 68,000 y BP, the climate of southeastern Vancouver Island was beginning to warm. At Cowichan Head and Cordova Bay the glaciomarine sediments of the Early Wisconsinan were overlain by a non-glacial, prograding, fluvial to deltaic sediments, herein termed unit E. The deposition of these fluvial to deltaic sediments were likely the result of a number of factors. First, isostatic rebound and a relative drop in sea level promoted aggradation due to base level change. Secondly, the melting Vancouver Island ice masses from the Early Wisconsinan likely increased fluvial output and thirdly, local fluvial channels may have shifted across the area.

During the Mid-Wisconsinan, the coastal lowland areas of Victoria and the Saanich Peninsula became sub-aerially exposed. Organic growth, and the detrital deposition of organics in bog and/or estuarine environments, were the dominant processes. These highly productive environments are well represented by unit E at Cordova Bay, Cowichan Head, Parry Bay and Muir Point. Dates from a paleosol at Cowichan Head, and thick organics at Parry Bay show a Mid-Wisconsinan climatic maximum between 35,600 and 40,000 y BP, after which, steady cooling eventually led to a Late Wisconsinan glaciation.

Late Wisconsinan - Quadra Sands, Proglacial (23,700 to 17,000 y BP) - Early Fraser Glaciation

The Late Wisconsinan is represented by a steadily deteriorating climate from at least 23,700 y BP to the onset of the Fraser Glaciation approximately 17,000 years ago. A unit of proglacial sand and gravel (unit F) was deposited across the eastern lowlands of southeastern Vancouver Island and the Georgia Strait, in front of advancing Vancouver Island and Cordilleran ice masses.

Late Wisconsinan - Vashon Till, Glacial (17,000 to 12,840 y BP) - Fraser Glaciation

By 17,000 y BP Vancouver Island ice flowed from the alpine to the lowland areas of the island and towards the Georgia and Juan de Fuca Straits, depositing the till of unit G. Ice from the Cowichan Valley moved southeastward across the north end of the Saanich Peninsula to form the drumlins at the Butler Brothers gravel pit, Martindale hill, Cowichan Head, and James and Sidney Islands. As the Cowichan Valley ice reached the Georgia Strait, it was redirected and eventually over-ridden by south-southwesterly flowing Cordilleran ice. The combined ice masses then flowed across the southern island and westward through the Strait of Juan de Fuca.

Late Wisconsinan - Capilano Sediments, Post-Glacial (12,840 to 11,700 y BP) - Late Fraser Glaciation

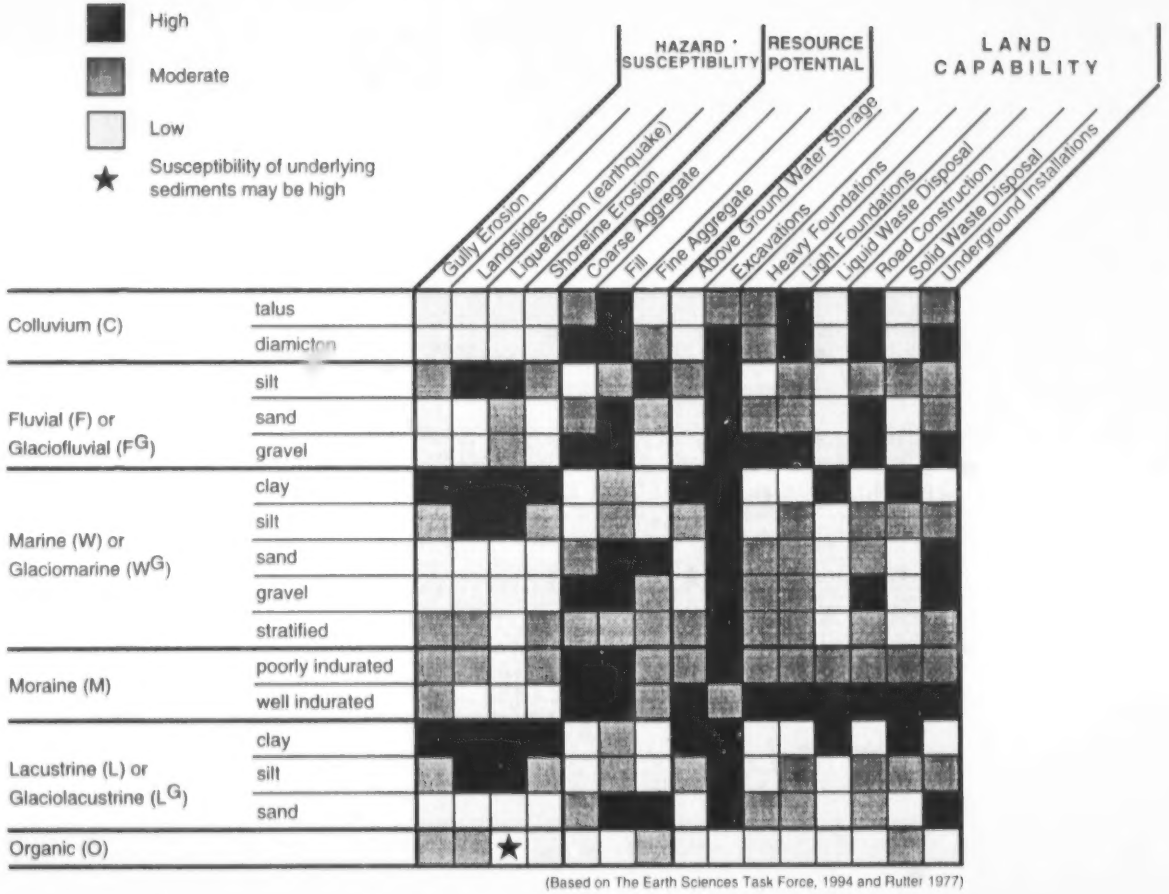
During Late Wisconsinan post-glacial time southeastern Vancouver Island was isostatically depressed a minimum of 85 meters below sea level. The combination of stagnating Vashon ice and marine incursion created thick deposits of poorly stratified and disturbed glaciomarine till (unit H), over much of lowland Victoria, Sooke and Ladysmith. Coastal areas located in front of actively downwasting ice masses such at the Cowichan Valley, Metchosin/Colwood delta and Muir Creek/Kirby Creek delta, received thick deposits of glaciofluvial deltaic, outwash sediments.

Holocene - Salish Sediments, Recent Non-Glacial (11,500 y BP to present)

By the time sea level had reached its present elevation, approximately 11,500 y BP, a new sequence of non-glacial processes had begun altering the post-glacial landscape. Soil began to form, and colluviation dominated the upland environments. Beaches began to form in the coastal areas and wherever surface depressions existed, lacustrine and bog deposition occurred (unit I). Approximately 6845 y BP, the eruption of Mount Mazama draped southeastern Vancouver Island in a thin white ash (unit I'), and the processes of deposition and erosion continue to affect the modern landscape today.

APPLICATIONS OF CURRENT RESEARCH

Quaternary geology plays an important role on southeastern Vancouver Island by providing much of the aggregate for roads, railways, airports, bridges and buildings. It forms the foundation material for buildings, tunnels and pipelines and the containing structures for water storage and waste disposal. Table 2 shows the engineering properties, hazard susceptibility and resource potential of the various surficial materials found on southeastern Vancouver Island, from the viewpoint of a geologist. It is designed to indicate the engineering characteristics and hazard susceptibility of the various sediments, yet not to take the place of the detailed site investigations performed by the engineer. As this table represents the properties of surface sediments it should be noted that sub-surface sediments, although closely associated with their surface counterparts, have been compressed by both overlying deposits and hundreds of meters of ice. The consolidation of sub-surface sediments makes them better load bearers than their surface counterparts, however, they are still susceptible to ground water drainage problems and failure. As the weight of a structure generally affects the sub-surface materials to a depth twice that of the structure's narrowest dimension (modified from Armstrong, 1984), the sediments underlying that structure must be evaluated throughout that expected depth of disturbance.



(Based on The Earth Sciences Task Force, 1994 and Rutter 1977)

Table 2: Engineering Applications of Current Research - Geologic units rated by hazard susceptibility, resource potential and land capability. Hazard Susceptibility increases with increased slope and decreases with compaction, consolidation and age.

Explanations and definitions of the information in table 2 are as follows:

Engineering Applications

Hazard Susceptibility - is the propensity or probability of a particular hazard to occur in any one sediment.

Gully Erosion: The susceptibility of sediments to gully erosion is based on their texture and cohesion.

Landslides: The propensity of the various sediments to fail under similar conditions (i.e. given equal vegetative cover, equal precipitation and ground water table, and equal slope).

Liquefaction: This process involves the loss of cohesiveness and shear strength of a soil due to increased soil water pore pressure resulting in the transformation of solid soil into a fluid mass. It generally affects cohesionless soils at, or near the water table and may produce ground oscillations, lateral sediment flow or sediment compaction (Earth Sciences Task Force, 1994). Liquefaction may be caused by an increase in soil water through seismic activity, a sudden ground water discharge or rapid loading.

Shoreline Erosion: Shoreline erosion is the relative measure of erodibility of sediments given equal coastal environmental conditions.

Resource Potential - is a relative measure of potential resource reserves according to deposit type and need.

Coarse Aggregate: Coarse aggregate (gravel) is rated according to the relative abundance of gravel versus silt, sand or clay.

Fill: Fill is rated according to its usefulness in general engineering procedures such as dam construction and road bed formation. Desirable fill characteristics include low shrink-swell potential, low compressibility, a low susceptibility to frost heave and a low plasticity (Rutter, 1977).

Fine Aggregate: Sand is the most commonly used fine aggregate and it is rated by its relative abundance over silt, clay and gravel.

Engineering capability - is defined here as the ability of various materials to accommodate various engineering practices.

Water Storage: Storage of water above the water table, in unlined surface reservoirs requires material with low permeability and little fracturing.

Excavations: Intense sediment consolidation and high boulder contents pose the majority of problems to excavation, therefore, ease of digging with conventional equipment is the major requirement for excavation capability and is used as the guideline for table 2. It should be noted that poor consolidation, slumping and ground water seepage are not taken into consideration in this table.

Heavy Foundations: Materials best suited for heavy foundations have a low compressibility a high shear strength when compacted and saturated, a high load bearing strength, a low shrink-swell potential and good drainage (Rutter, 1977; Armstrong, 1984).

Light Foundations: Materials suitable for light foundations are similar to those chosen for heavy foundations, however the load bearing strength is not quite as important.

Liquid Waste Disposal: The controlling factors for liquid waste disposal are sediment texture, permeability and water table proximity. Sites are chosen for minimum seepage, a deep water table and minimum overland flow. Regions of groundwater discharge are preferred over recharge areas and long term ground stability is also necessary for liquid waste disposal.

Road Construction: Material with the best rating for highway, railroad and airfield construction is that which produces a stable base material. It must have a low compressibility, a high shear strength when compacted and saturated, and a low shrink-swell potential (Rutter, 1977).

Solid Waste Disposal: The general rule for the location and containment of solid waste disposal sites is to treat them as liquid waste disposal sites. The decay of garbage and metal produces similar by-products as liquid waste, yet at a slower rate.

Underground Installations: Underground installations include tunnels, cable lines and pipelines which require good drainage, low shrink-swell potential and high load bearing strength.

Aggregate Resources

The major sand and gravel deposits on southeastern Vancouver Island were formed either as pro-glacial outwash from the advancing Cordilleran and Vancouver Island ice masses of the Fraser Glaciation, or as sandur and deltaic deposits formed during the recession of the Fraser glaciation and the coastal emergence that followed. The economic viability of these aggregate deposits has been established in Metchosin, Langford, Goldstream, Duncan, Cordova Bay, Saanichton, and North Saanich and in parts of the Cowichan Valley, where they provide aggregate for much of southern Vancouver Island and southwestern British Columbia.

The lithologic units containing relatively abundant aggregate deposits include the Quadra sands (unit F), the Capilano sediments (unit H), and the Cowichan Head Formation (unit E, fig. 26). Potential surface aggregate sources are identified throughout the Cowichan Valley, in the upper regions of the Goldstream Valley and the Muir Creek/Kirby Creek delta. In addition, sandy surface tills with non-debris flow origins and with matrices containing more than 70 per cent sand are considered good targets for sand and gravel exploration.

SUMMARY AND CONCLUSIONS

The objectives of this research were firstly, to construct comprehensive surficial geology maps of southeastern Vancouver Island and the Gulf Islands, with particular emphasis placed on the Saanich Peninsula, a region not mapped since 1913. Secondly this research was conducted to characterize the stratigraphy of the region, using physical, textural and lithologic parameters, and to correlate this stratigraphy in order to reevaluate the Quaternary history of southeastern Vancouver Island. Finally, this research was conducted to evaluate the aggregate resources and ground hazards of southeastern Vancouver Island.

The surficial geology of southeastern Vancouver Island is mapped and published as six, 1:50,000 scale maps (Blyth and Rutter, 1993 a, b, c, and d; Blyth *et al.* 1993; and Rutter and Blyth, 1993, appendix F in map pocket). These maps include information on deposit characteristics, dominant deposits by map sheet and a brief Quaternary history. In addition, a preliminary review of the Quaternary geology of southeastern Vancouver Island and the Gulf Islands is published as a British Columbia Ministry of Energy, Mines and Petroleum Resources Geological Fieldwork Paper (Blyth and Rutter 1993e). These data, combined with twelve key sections and twenty absolute dates, are used to expand the regional Quaternary history and to identify the aggregate resources of southeastern Vancouver Island. Potential aggregate sources exist in the Cowichan Valley, the upper Goldstream Valley and the Muir/Kirby Creek delta.

Upon reviewing the Quaternary stratigraphy of southeastern Vancouver Island three glacial and three non-glacial periods are identified (fig. 51). The Quaternary history of southeastern Vancouver Island begins with pre-Sangamon glacial and possibly non-glacial sediments of a mostly Vancouver Island provenance. These deposits are followed by Sangamon (Muir Point Formation) Interglacial fluvial to estuarine sediments deposited around 119,000 to 112,000 y BP. The Early to Middle Wisconsinan, between 112,000 y BP and approximately 68,000 y BP is represented by fluvial and glaciomarine deposition of Dashwood drift, also originating from Vancouver Island. The Middle Wisconsinan is identified by non-glacial, sub-marine to sub-aerial sediments of the Cowichan Head Formation deposited between 68,000 and 23,700 y BP. After a Mid-Wisconsinan thermal maximum around 39,000 y BP, the climate appears to have steadily deteriorated until the appearance of proglacial sand and gravel (Quadra sands), from the advancing Fraser and

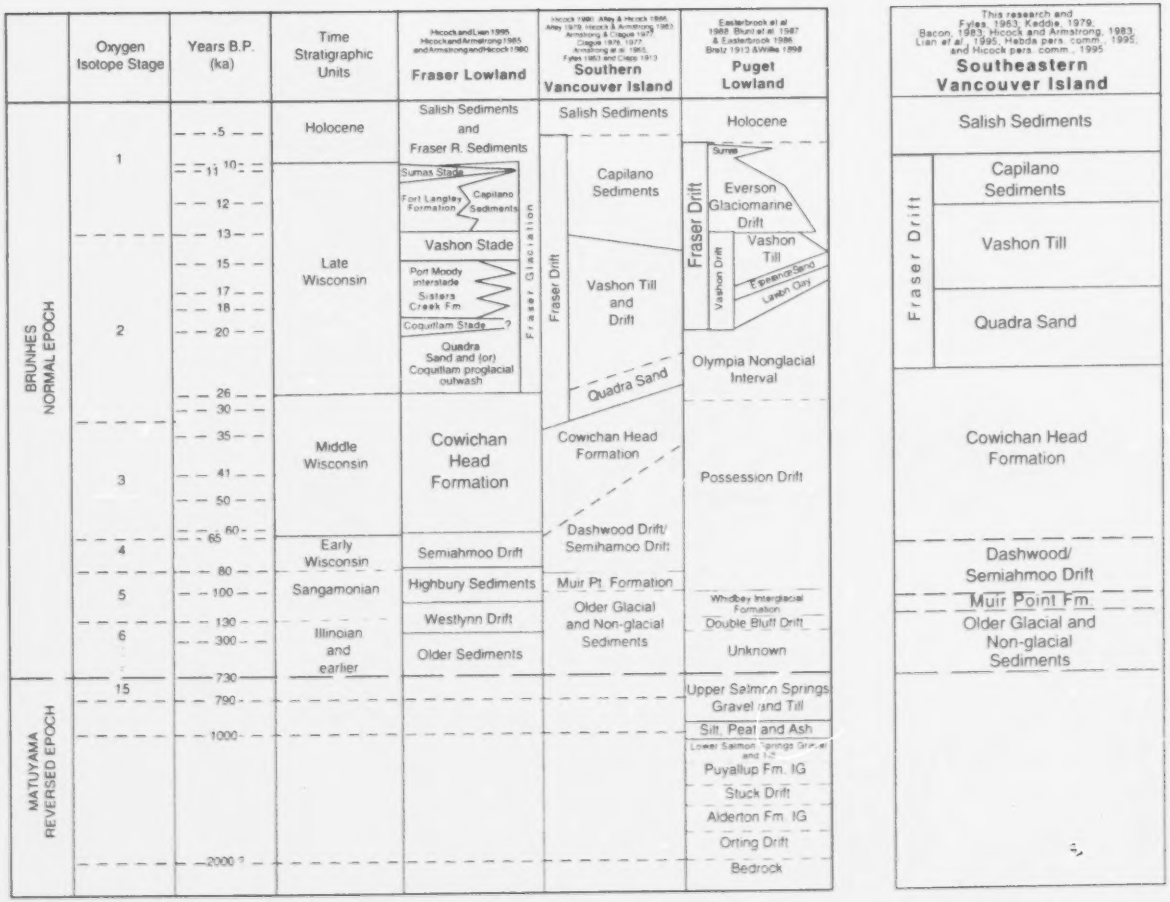


Figure 51: The stratigraphy of Southeastern Vancouver Island, the Fraser and Puget Lowlands.

Vancouver Island ice masses, approximately 23,700 years ago. Between 17,000 and 12,840 y BP, southeastern Vancouver Island was covered by no less than 1,524 meters of ice which passed southwestward across the southern tip of Vancouver Island and towards the Strait of Juan de Fuca. The area was ice free by approximately 12,840 y BP when the processes of deglaciation resulted in the deposition of thick glaciomarine and glaciofluvial sediments (Capilano sediments). The Holocene on Vancouver Island is represented by the present day processes of upland colluviation, beach formation, terracing, pedogenic processes, and lacustrine and bog formation.

Till characterization using textural and lithologic evidence provided variable results. Rapid facies change over short distances made textural characterization of Vancouver Island tills difficult, however, textural analysis shows glacial debris flows to be sandier than glaciomarine tills, while tills deposited over sand and gravel are more sandy than those deposited over bedrock. A finer sampling program may provide more accurate results, and may even provide information on sub-surface aggregate deposits. Till characterization using lithologic characteristics, appears to indicate Vancouver Island tills to be more mafic than Cordilleran tills, however, to more accurately reflect the complex bedrock geology of Vancouver Island and the Cordilleran, multiple samples per unit should be taken using a systematic sampling pattern at a scale larger than 1:50,000.

Ice flow directional indicators, such as fabric, appear to be the best sign of ice movement at the advanced stages of glaciation, while bedrock striae and flutings appear better at showing early glacial ice movement. The discordant Late Wisconsinan ice directional indicators, such as fabric and drumlins, versus rock striae and flutings, show Vancouver Island ice to have probably covered the coastal lowland areas of Ladysmith and the northern Saanich Peninsula, prior to converging with Cordilleran ice near Sidney Island.

New dates from this and other recent studies have narrowed the age ranges of the Capilano sediments, Vashon Till, Dashwood Drift and the Muir Point Formation; and extended the estimated ages of the Quadra Sand, Cowichan Head Formation and the Salish Sediments on southeastern Vancouver Island. In addition new radiocarbon dates from this research, at Parry Bay, in combination with a previous date from a paleosol in the middle of the Cowichan Head Formation suggest a Mid-Wisconsinan climatic maximum, in this area, of approximately 39,000 y BP.

Future Research

To further understand the Quaternary geology of southeastern Vancouver Island, systematic fabric, textural, lithologic and geochemical sampling should be carried out at a scale larger than 1:50,000. A greater number of bracketing dates are needed to more accurately determine the onset of the Fraser glaciation, the advance of the Quadra sediments, and the deposition of Dashwood drift. Finally, the origin of the raised beaches on the eastern coast of Vancouver Island and in the Gulf Islands should be established.

The next step in utilizing the Quaternary information of southeastern Vancouver Island should be the incorporation of drill core data and bedrock topography to provide a three dimensional view of the Quaternary deposits. This information should then be assessed to determine probable zones of liquefaction, failure plains, aquifers and likely underground sources of aggregate.

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APPENDICES

Appendices A: Stratigraphic Sections

Appendices B: Lithology

Appendices C: Texture

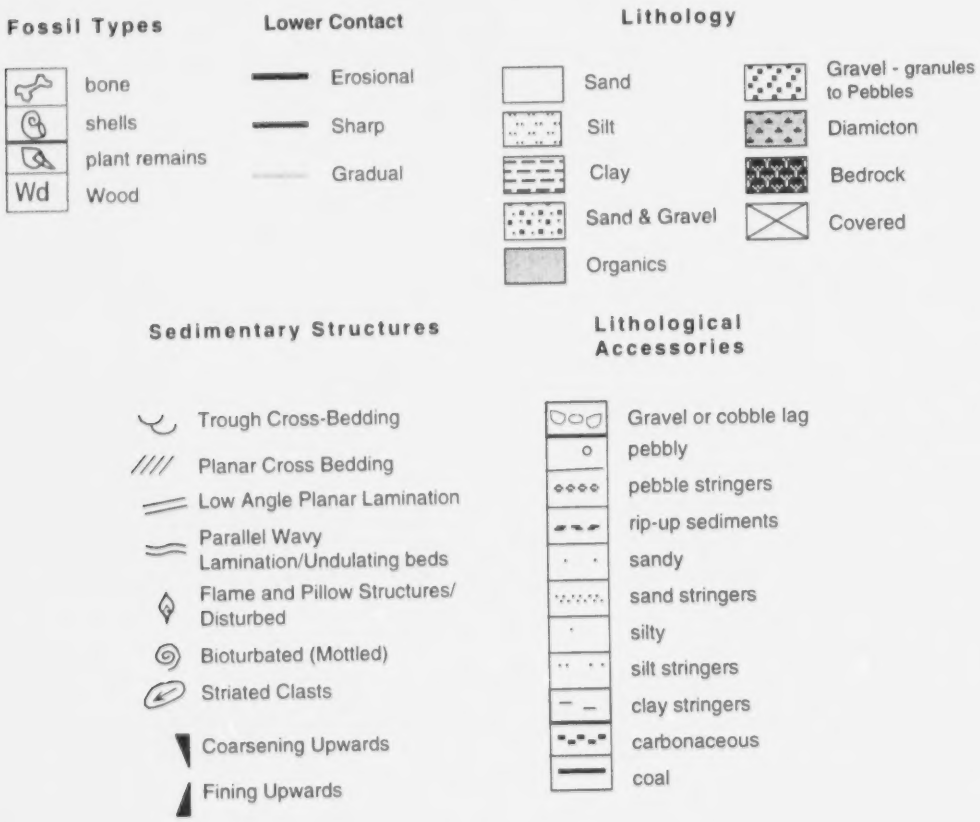
Appendices D: Fabric

Appendices E: Field Records

Appendices F: Surficial Geology Maps of Southeastern Vancouver Island - Located in map pockets

APPENDIX A: Section Descriptions

Southeastern Vancouver Island Stratigraphic Symbols - Legend



Appendix A: Section Descriptions

THE BEACON HILL/FINLAYSON POINT SECTION
(48°24'25"N, 123°21'50"W)

Access: Finlayson Point, which is the basal exposure of this section, is located approximately five kilometers southeast of downtown Victoria and is accessible via the beach accesses at the southern end of Cook street. The upper portion of this section is located ~1 kilometer east of Finlayson Point at the Beacon Hill cliffs between Finlayson Point and Clover Point.

Geomorphology: The area surrounding the cliffs at Beacon Hill is blanketed with silty to sandy diamicton and is expressed as a rolling topography . The exception to this topography are the hummocky bedrock highs which have shed their morainal covers to reveal either bare bedrock or bedrock with a thin morainal veneer.

Unit Summaries:
Refer to Figure : The Beacon Hill/Finlayson Point Section

Composite Section HB92-01, 74 & 75

Bedrock - Gneissic, fluted and striated. There appear to be two sets of striations, one old and cut through and one set much more fresh and unaltered. (see photos R4 34-36)

	Flutings	Young Striae		Old Striae
	022°	007°		017°
	020°	002°		029°
	016°	013°		001°
	024°	017°		019°
	016°	019°		010°
Average	**19.6°**	013°	Average	**15.2°**
		013°		
		016°		
		036°		
		036°		
	Average	**17.2°**		

Interpretation: This appears to be bedrock of the Early Paleozoic, Wark Gneiss Formation which consists of massive and gneissic metadiorite, metagabbro and amphibolite (Muller 1980).

Unit 1 (~8 m): Silty diamicton at Finlayson Point (HB92-74): dark greyish brown (Munsell 2.5Y 4/2); moderately indurated (i.e. relatively difficult to break by hand); 5-10% clasts, 90-95% matrix; matrix - 2-5% clay, 40% silt, 25% fine sand, 20-25% medium sand and ~15% coarse sand (hand textured); clasts rounded to well rounded, average 1 cm a-axis diameter, maximum size is approximately 5 cm a-axis diameter. This unit may contain shells but due to its location near sea level they may be post depositional. The upper portion of this unit was measured ~8 meters above mean high tide at the Beacon Hill Cliffs (HB92-75). The upper 40 cm is a medium to coarse sandy diamicton. It is dark grey (Munsell 10 YR 4/1 moist), matrix supported and massive in the west and containing undulating sand and gravel lenses in the east. It is 80% matrix and 20% clasts. The matrix is approximately 5% silt, 50% medium sand and 45% coarse sand; the clasts are mostly sub-rounded but range from sub-angular to well rounded; the maximum clast size is ~5 cm a-axis diameter, the average size is 0.5-1 cm a-axis diameter. The lower contact is covered at the Beacon Hill cliffs and exposed and erosively contacting bedrock at Finlayson Point.

Unit 1:
Interpretation: The poor sorting, moderate induration and contact directly on striated bedrock at the base of this unit suggests a subglacial origin, however, its proximity to the ocean and the existence of shells cannot rule out marine contact. The fine textured matrix at the base implies either subglacial or glacial marine influence. The undulating or disturbed sand and gravel lenses at the eastern end of this section show a possible combined depositional environment of subglacial melt out and lodgment.

Unit 2 (0.2 m): Medium to coarse sand with rare cobbles; it is a dark greyish brown (Munsell 2.5 Y 4/2 moist). It is massive with no discernible bedding; 90-95% sand and 5-10% clasts. The clasts average 0.5-1 cm but maximum clast size is ~20 cm a-axis diameter. The lower contact is abrupt or sharp.

Interpretation: The massive nature of this deposit is most likely the result of rapid deposition such as can be found in a gravity flow (Miall 1992) or rapid melt-out environment. The material is relatively well sorted except for the rare pebble and cobble which indicates either drop stone deposition from ice rafting or debris flow incorporation of fluvial lag deposits.

Unit summaries continued...

Unit 3 (2.5m): Medium to coarse sandy diamicton: olive in colour (Munsell 5Y 5/6 moist). Matrix supported with 90% matrix and 10% clasts; matrix is 2-5% silt and fine sand, ~60% medium sand and ~35% coarse sand (Note: matrix texture tends to fine upward); clasts are angular to sub-rounded, with rare rounded ones; maximum clast size 15 cm a-axis diameter, average size 1 cm a-axis diameter, granite present throughout and rare striated clasts throughout. This unit contains a gravel lens ~12 cm thick. This lens is matrix supported and contains 80% coarse sand and 20% small pebbles; it is moderately sorted to massive and undulates in a concave to convex manner as it pinches out towards the east. The lower contact is erosive.

Interpretation: The sandy nature of this diamicton may be partly a result of a coast mountain (granitic) source and partly from gravity flow sorting. Mass movement with intermittent fluvial sedimentation and a generally fining upward nature, may also explain the undulating gravel lenses. This unit appears have been deposited in an ice marginal, probably proglacial, environment.

Unit 4 (1.9 m): Interbedded fine to coarse sand with gravel lenses. The sand is very well sorted and is generally medium to coarse at the base and fining upwards to a finer sand and fewer gravel lenses; it exhibits planar cross bedding and has an apparent dip of ~15° towards 305° facing north; the unit is matrix supported (50-90% sand), even in the gravel lenses. The gravel lenses are moderately sorted and contain sub-rounded to rounded pebbles and coarse sand. Large clasts are rare. The lower contact is gradual. Note: Glaciomarine silt found above the lodgment till, approximately half a kilometer north of Finlayson Point, has been dated at 12,100 +/- 160 (GSC 1114).

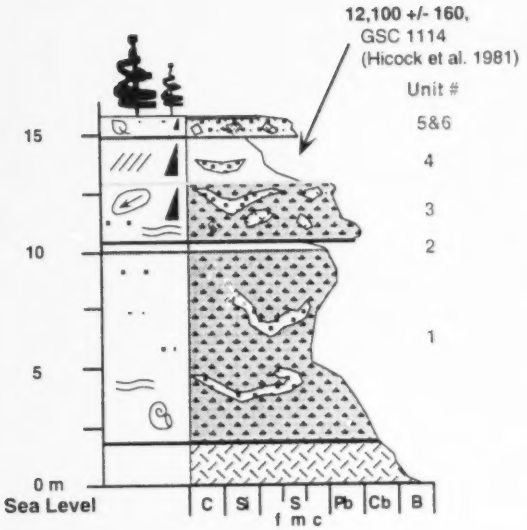
Interpretation: Clast rounding size and sorting suggest that this unit was most likely deposited in a relatively low fluvial flow regime, possibly as a transverse bar or sand wave. The presence of moderately sorted gravel lenses also suggests linguoid, transverse bar or remnant lag deposition.

Unit 5 (0.7 m): Sand and gravel; no colour taken but see photo R5-2; crudely bedded, poorly sorted within the beds; matrix supported, matrix coarse sand; clasts granules and small pebbles; maximum clast size 20-30 cm a-axis diameter, the larger clasts are mostly granite and basalt, the average clast size is 1-2 cm, fining upward (Note: this unit contains larger clasts than the basal units). [See photo R5-2]. The lower contact is abrupt.

Unit 5
Interpretation: The poor sorting, abrupt lower contact, cobble base and general fining upward nature would relate this deposit to a debris flow.

Unit 6: Brunisolic soil on massive sand and gravel, dark brown, well developed, see photo R5-2. The lower contact is gradual and is a part of unit 5.

THE BEACON HILL/FINLAYSON POINT SECTION
48°24'25"N 123°21'50"W



Unit 5 & 6 (0.7 m) : Crudely bedded sand and gravel with well developed soil on top

Unit 4 (1.9 m) : Interbedded fine to coarse sand with moderately sorted gravel lenses

Unit 3 (2.5 m) : Sandy diamicton, fining upward matrix; granite and rare striated clasts throughout; also contains one undulating gravel lense

Unit 2 (0.2 m) : Medium to coarse sand with rare cobbles; massive

Unit 1 (~8.0 m) : Silty diamicton, coarsening upward; contains rare shells at base; also contain disturbed lenses of sand and gravel towards the east

Bedrock: Fluted (19.6°) and striated: Old (15.2°); Younger (17.2°)

BUTLER BROTHER'S GRAVEL PIT SECTION
(48°33'45"N, 123°25'25"W)

Access: This section is located at the west end of the town of Keating Cross Roads.

Geomorphology: Between highway 17 and the Central Saanich Municipal gravel pit you are on the first in a series of five ridges. These northwest to southeast trending ridges begin at the Central Saanich/Butler Brothers gravel pit and ends eleven kilometers to the northeast with the fifth ridge which forms the sandy cliff on the southeast end of Sidney Island. The Central Saanich/Butler Brothers gravel pits expose the inside of the most westerly of these drumlins.

Unit Summaries:
Refer to Figure 3.4: The Butler Brothers composite section [see photos R4 17-21, R6 32-37 and R7 4; Sample HB92-S60/6 and Fabric HB92-108/5]

Composite Section HB92-108

Unit 1 (0-0.7m): Sand and gravel - interbedded, planar cross-bedded with an apparent dip of 14° towards 235° ; the sand layers are medium to coarse in texture and average 20 cm in thickness; they are well sorted and repeatedly fine up section. The gravel beds erosively contact the lower sand layers and are initially mixed with sand; the clasts average 2 cm but grade up section to openwork beds with clasts averaging only 1.5 cm a-axis diameter. Manganese staining is present throughout the unit, especially in openwork gravels. The lower contact is covered.

Interpretation: The well sorted sand and gravel indicates a moderate to low energy fluvial system. The steeply dipping, planar cross-bedding is indicative of either linguoid or transverse bar deposits, or may represent deltaic foreset bedding. The erosive contact between the gravel and lower sand beds is probably a result of shifting fluvial channels; first cutting into the poorly consolidated sand beds, then reaching equilibrium and depositing gravel and finally depositing sand as the channel shifts away and the rivers energy is diverted. Thus I believe this to represent linguoid, transverse bars and sand waves in a relatively low flow regime.

Unit 2 (~0.3m): Sand and gravel - well sorted and rounded, horizontally to sub-horizontally bedded; the unit contains rare lenticular concentrations of openwork gravel with clasts up to 2-3 cm a-axis diameter. The lower contact is erosive and planar.

Interpretation: The well sorted sand and gravel also appears to have a fluvial origin, however, the planar base and horizontal bedding suggests a more constant flow punctuated by rare channel shifts as seen by the openwork gravel lenses. These gravel lenses may also have been deposited after the horizontal sand and gravel beds were laid down, however, more detailed information would be needed.

Unit 3 (~14m): Gravel - well rounded to sub-rounded; average clast size approximately 1 cm a-axis diameter; bedding is openwork, planar cross-bedded with two apparent dips of: 25° towards 165° and 19° towards 112°. Manganese staining is present throughout. The lower contact is covered by road fill.

Interpretation: This gravel appears to have been deposited in a moderately high energy fluvial environment, most likely as deltaic foreset beds or as a large transverse bar deposit. The apparent bedding suggests a northwesterly source.

Unit 4 (~10m): Sand and gravel; trough cross-bedded and moderately well sorted; the average clast size is 2 cm, clasts are sub-well rounded, rare 25 cm a-axis maximum clasts are present. The gravel remains roughly the same size throughout the section, however, there is an increase in the number and size of the sand lenses present. The sand lenses average 5 meters wide and 60 cm thick and are well sorted and medium to coarse textured. The bedding within the sand lens is generally planar, dipping 9° towards 112° when facing 015°N. The lower contact is sharp and erosional. [see photos R6-32 which faces northward; R6-33 which faces towards 268° and the Central Saanich Municipal gravel pit; R6-34 and 35 which face toward 351° .

Interpretation: Minor channel fills i.e. as in a braided stream environment.

Unit summaries continued...

Unit 5 (4-5m): Sandy diamicton - olive in colour (Munsell 5Y 5/3); 60% matrix, 40% clasts; the matrix is approximately 30% medium sand and 70% coarse sand (hand textured) average clast size is 2-3 cm, maximum clast size 20-30 cm and decreasing towards the top of the unit, clasts sub-rounded to well rounded; there does appear to be weak stratification in the form of 20 meter wide and 3 cm thick, lenses of silt and coarse sand increasing within the diamicton up section. [see Fabric HB92-108/5] The clast lithology is mostly diorite, granite, amigdaloidal basalt and rare sandstone. (See photos: R6-36 which shows the contact between unit 4 and unit 5 1-1.5 meters above the white clast; R6-37 which shows a seepage zone between the diamicton of unit 5 and the sand and gravel of unit 4; and R7-1 which show the contact between a sand lens in unit 4 and the sandy diamicton of unit 5). The lower contact is erosional. [Note: probably the same diamicton described as unit 5 in the Central Saanich gravel pit 1 km westward]

Interpretation: The interbeds of sand and coarse nature of this deposit suggests a subaerial flow till or debris flow origin, interbedded with glacial fluvial outwash. Fabric suggests a westerly source, however, the sample is too small to draw conclusive interpretations.

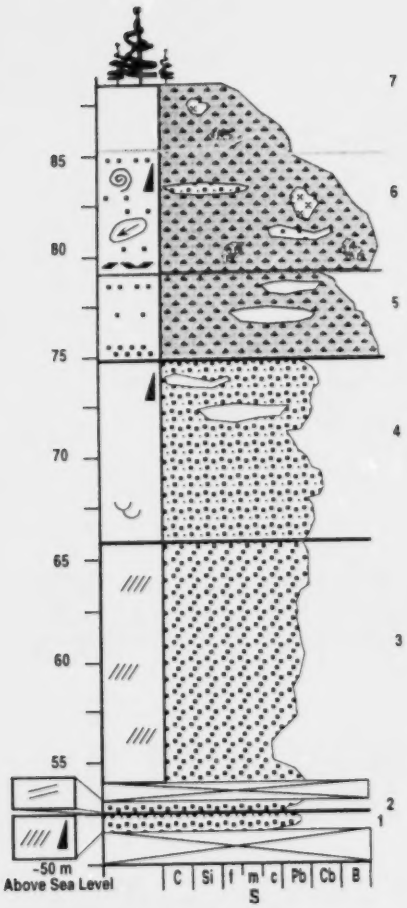
Unit 6 (~6m): Very sandy diamicton; dark greyish brown in colour (Munsell 10 YR 4/2); poorly to moderately consolidated and interbedded with poorly sorted sand and gravel beds and what appear to be rip-ups of silty material. The diamicton is matrix supported, ~85% matrix and 15% clasts; the matrix is <2% fine sand, ~80% medium sand and ~18% coarse sand. Clasts average in size from 2-3 cm but rare striated boulders of diorite, granite, amigdaloidal basalt and concretionary sandstone are found predominantly at the base of the unit. Most clasts in this unit are pebble and cobble size and decrease in size towards the top of the unit, they are rounded to sub-rounded and vary in lithology similar to unit 5. There are increasing silt laminations in the top 2 meters which average in thickness from 0.2-0.5 cm. They are very faulted and disturbed and still contain sand and diamicton between the laminations which averages around 4 cm in thickness. In the top 0.5 meters silt-clay laminations increase and are increasingly well bedded. The sand and gravel beds are matrix supported; average 3-20 cm thick, are moderately to poorly sorted and contain clean coarse sand (80-90%), and small pebbles (~10%). The lower contacts are abrupt and slightly erosive. The 'rip-ups' are lenses to almost clasts of unconsolidated, disturbed clay, silt and fine sand. The clay is pale grey-brown and the silt and fine sand is brownish (no Munsell taken). The lower contact for this entire unit is gradual.
(See photo R7-2 and 3 of contact zone around unit 5).

Interpretation: Most likely of flow till origin deposited by supraglacial mass movement with intermittent fluvial activity.

Unit 7 (~0-4m): This unit is an iron stained continuation of unit 6 and as noted at the Central Saanich gravel pit, appears thicker in lowland areas than in upland areas.

Interpretation: This is most likely an area of groundwater discharge or simply zone of oxidation.

BUTLER BROTHERS SECTION
48°33'45"N 123°25'25"W



Unit 7 (~0-4 m): An iron stained diamicton; apparently a continuation of unit 6; its undulating base follows depressions in ground surface

Unit 6 (~6 m): Very sandy diamicton interbedded with poorly sorted sand and gravel beds and rare silty 'rip-ups' throughout; rare striated boulders can be found near the base; silty disturbed and faulted laminations increase towards the unit's top

Unit 5 (4-5 m): Sandy diamicton; weakly stratified with lenses of silt and coarse sand increasing up section and clast size decreasing up section

Unit 4 (~10 m): Sand and gravel; moderately well sorted but with an increase in the number of sand lenses towards the top; the lenses are planar cross-bedded throughout

Unit 3 (~14 m): Gravel; generally openwork; planar cross beds have two apparent dips one of 25° towards 165° and the other of 19° towards 112°; manganese staining is present throughout

Unit 2 (~0.3 m): Sand and gravel; well sorted and sub-horizontally bedded with rare openwork gravel lenses

Unit 1 (~0-0.7 m): Interbedded sand and gravel; planar cross bedding has an apparent dip of 14° towards 235°

CENTRAL SAANICH GRAVEL PIT SECTION
(48°33'40"N, 123°25'45"W)

Access: This section is located approximately 2 kilometers west of highway 17, one kilometer west of the Butler Brother's gravel pit, along Keating Cross Road.

Geomorphology: Between highway 17 and the Central Saanich Municipal gravel pit you are on the first in a series of five ridges. These northwest to southeast trending ridges begin at the Central Saanich/Butler Brothers gravel pits and ends eleven kilometers to the northeast with the fifth ridge which forms the sandy cliff on the southeast end of Sidney Island. The Central Saanich/Butler Brothers gravel pits expose the inside of the most westerly of these drumlins.

Unit Summaries:
Refer to Figure 3.5: The Central Saanich section
Section HB92-70; Samples HB92 S30 for ^{14}C, S34& S35/U4 for fabric, texture and lithology, [see photos R4 17-21]

Bedrock (2-5 m): Chloritic; talc rich iron rich dioritic intrusive The unit appears to dips 43° towards the 110° east. [see photos R4 - 22-24]

Interpretation: Bedrock of the Lower to Middle Jurassic Island Intrusions. These intrusions are generally composed of granodiorite and quartz diorite. The apparently hydrothermal alteration may be a result of this section's close proximity to a fault (Muller 1980).

Unit 1 (0.65 m): Sandy silt - iron stained, horizontally bedded to massive, sandy silt which is mostly dark yellowish brown (Munsell 10 YR 4/4), however, there are some darker segments which contain coal or burnt organics which are a very dark greyish brown (Munsell 10 YR 3/2). It is 85 per cent matrix supported 15 per cent of which is clay, 50-60 per cent silt and approximately 30 per cent fine sand (hand textured). Note: the dark fragments are just above or below the angular rocks. The clasts are all very angular and altered, iron rich dioritic intrusive; the biggest is approximately 10 centimeters at its a -axis diameter and size and frequency diminish upwards. The lower contact is erosional but contains approximately 15 per cent angular clasts of very localized bedrock which diminishes towards the top of the unit.

Interpretation: Flood overbank or backswamp deposit.

Unit 2 (0.35 m): Sand - massive to horizontal bedded, light olive brown (Munsell 2.5 YR 5/4) without clasts; less than 2 per cent clay, approximately 20 per cent silt and 80 per cent fine sand. The lower contact appears gradual to undulating with flame structures.

Interpretation: Flood overbank or back swamp.

Unit 3 (0.5-5 m): Sand and gravel - horizontal to trough cross-bedded medium to coarse grained sand and gravel with rare cobbles at the base of the troughs ; sand beds have large pebbles throughout, clasts are mostly rounded to sub-rounded. The lower contact is gradual to abrupt.

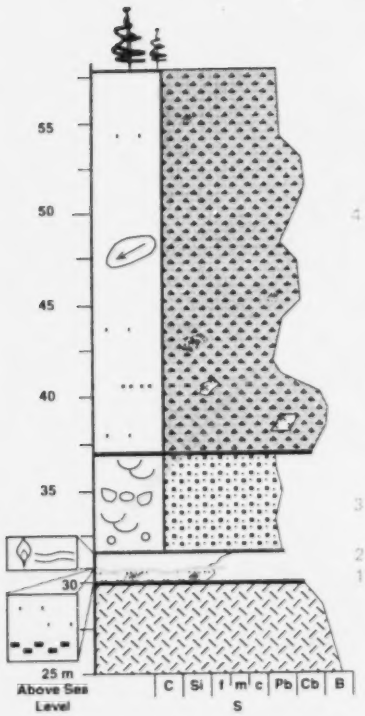
Interpretation: The trough cross-bedded sand and gravel appears to be from a low to moderate flow regime with high bedload and shifting channels. Most likely fluvial dunes with minor channel fills.

Unit 4 (5-20 m): Diamicton - fine, sandy, olive grey (Munsell 5Y 4/2), with rare silt stringers; 85-90% matrix, 10-15% clasts; matrix 5% fine sand, 25% medium sand and 70% coarse sand (hand textured) see sample HB92-S35; clasts are mostly rounded to subrounded and well striated, they also covered in a thin clay coating; the clast lithology is 31% basalt, 15% plagioclase porphyry, 14% mafic volcanic, 14% siltstone, 12% diorite, 6% siltstone and minor amounts of quartz, gneiss, red chert, breccia, granite and potassium-feldspar porphyry; the fabric dips towards the north. The lower contact is erosive.

Interpretation: The striated clasts and the strong fabric in this diamicton show a glacial origin, however, the clay skins and the rare silt stringers indicate some reworking. This unit appears to represent a mixture of meltout till, deposited at the glacier's base and subglacial lodgment till. The fabric indicates a northern source which is backed up by the lithology which suggests a Vancouver Island to Georgia basin origin.

THE CENTRAL SAANICH GRAVEL PIT SECTION

48°33'40"N 123°25'45"W



Unit 4 (5-20 m) : Diamicton; fine sandy, olive grey well striated clasts, many covered in a thin clay coating; the fabric dips approximately 10° towards 014°

Unit 3 (0.5-5 m) : Sand and gravel; medium to coarse grained, with rare cobbles at the base of the troughs; the lower contact contains flame stuctures

Unit 2 (0.35 m) : Sand; massive to poorly horizontally bedded

Unit 1 (0.65 m) : Sandy silt; horizontally to massively bedded; dark yellowish brown with coal or burnt organics; rare angulardioritic pebbles deminishing up section

Bedrock (2-5 m) : Altered diorite

THE CHEMAINUS RESERVE SECTION
(48°59'40"N, 123°46'20"W)

Access: This section is approximately three kilometers northeast of the town of Ladysmith

Geomorphology: The topography is gently rolling and ridged in a northwest-southeast trending direction following the strike of the Nanaimo sedimentary bedrock.

Unit Summaries HB92-10:
Refer to Figure 3.6: The Chemainus Gravel Pit Section - see photos R1 #15 facing 72°, scale 2 meters high; #16 towards 136°, #17 shows thrust faults in sand

Bedrock: Sandstone bedrock striated at approximately 138°.

Interpretation: Bedrock of the Upper Cretaceous Nanaimo sedimentary group (Muller 1980).

Unit 1 (~3m): Interbedded sand and gravel - planar cross-bedding, apparently dipping 44° towards 166°. Clasts are rounded to subrounded and well sorted. The lower contact is directly on bedrock.

Interpretation: The well sorted and rounded clasts combined with the steeply dipping bedding towards the southeast, implies a fluvial origin; most likely foreset beds from a deltaic front originating in the northwest but possibly from a longitudinal bar.

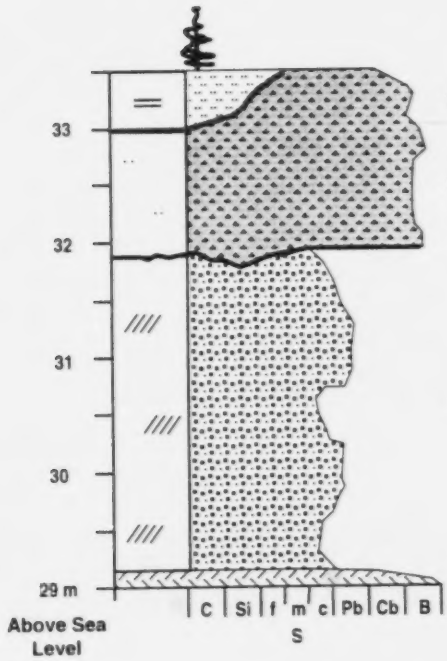
Unit 2 (1-1.5m): Silty diamicton - moderately indurated and massive, unconformable overlying the sand and gravel.

Interpretation: Lack of detail prevents an accurate interpretation, however, the silty nature of this diamicton, combined with its moderate induration, massive structure and lack of present day source suggest a glacial origin.

Unit 3 (0-2m): Silt and clay - a discontinuous lens of horizontally interbedded, finely laminated sediments approximately six meters across. The lower contact is sharp but apparently conformable.

Interpretation: The fine texture and horizontal bedding in this deposit suggests a subaqueous depositional environment. The unit is not sorted, nor continuous enough to be aeolian. Its discontinuous lateral extension and clear bedding suggests a lacustrine origin rather than marine. This unit mostly likely represents a small pond deposited directly on the lower diamicton i.e. a backswamp deposit (Miall 1992).

CHEMAINUS RESERVE SECTION
48°59'40"N 123°46'20"W



Unit 3 (0-2 m): Interbedded silts and clays within a large trough shaped depression of unit 2

Unit 2: (1-1.5 m) Indurated diamicton, uneven or disturbed, erosional lower contact

Unit 1 (~3 m): Sand and gravel - interbedded, planar cross-bedded and steeply dipping, with an apparent dip of 44° towards 166°; faults have offset much of this unit

Striated (138°) sandstone bedrock

CORDOVA BAY COMPOSITE SECTION
48°29'40"N, 123°19'25W

Access: This section is located in the crook of Cordova Bay approximately 9 kilometers east-northeast of Victoria. It can be easily accessed through Mount Douglas Park by taking a short (~1 km) hike east along the beach.

Recent storm waves have eroded the northern facing shoreline to expose different units of the section in different areas along the bay to create the composite section shown in Figure 3.7.

Geomorphology:

The Cordova Bay Section is situated within the same drumlin that contains the Cowichan Head Section. The drumlin runs in a north-northwesterly direction, along the eastern coast of the Saanich Peninsula and was apparently formed by ice from the Cowichan Valley on Vancouver Island. The land that forms this drumlin has been isostatically depressed and preserved below or near sea level during glaciations and subaerially exposed during non-glacial times, thus recording an extensive sequence of glacial and non-glacial sediments.

Unit Summaries:

Refer to Figure 3.7: Composite Section HB92-78 and HB92-120.5 and HB95-1. See R5-4 and photos from 1995-1 #29-32.

Bedrock (0-3m): Mafic volcanic striations average 175° towards the south.

Interpretation: Bedrock of the Permian or Triassic, unnamed volcanics consisting of basaltic dacitic lava, breccia and tuff and minor limestone (Muller 1980). This section is also very near, or on, a bedrock unit of Lower Paleozoic Colquitz Gneiss; which is a quartz-feldspar gneiss (Muller 1980). Striae on the volcanics indicate a southerly ice flow.

Unit 1 (~4 m) Silty diamicton, blue-grey (no Munsell colour taken) with pebbles, striated cobbles of basalt and diorite; shell fragments and rare intact shells present throughout; rare clay rich lenses can be found throughout the unit. No visible bedding can be distinguished - massive except for 0.5-1 meter wide, undulated lenses of poorly sorted, sub-rounded gravel with shells. The lower contact is covered by modern beach deposits. The matrix consists of approximately 5 per cent clay, 48 per cent silt and 47 per cent fine sand.

Interpretation: Glacio-marine till with dropstones and sub-glacial sediment drop out. This unit appears similar to that found near the base of the Cowichan Head section and probably represents the Dashwood drift of the Early Wisconsinan.

Unit 2 (1 m): Coarse sand and gravel, poorly sorted, poorly bedded and mostly matrix supported, with minor amounts of silt; Clasts include rare, disintegrating granites and are generally subangular to sub-rounded and flat lying. The base of this unit contains well sorted lenses of oxidized medium sand interbedded with fine sand and silt approximately two meters wide and 0.30 m thick. The lower contact is erosional.

Interpretation: This unit may represent a near source, sub-aqueous debris flow; possibly related to increased fluvial activity.

Unit 3 (2-3 m): Coarse sand to blue-grey silt, fining upward and slightly oxidized and containing 3 cm a-axis diameter, sub-well rounded pebbles throughout. The bedding is roughly horizontal. The lower contact is gradational.

Interpretation: A subaqueous probably sub-marine low energy deposit. The pebbles may be glacial in origin, however, disturbed bedding was not noted therefore they may represent beach lag.

Unit 4 (~6 m): Planar cross bedded, well sorted, sand and gravel with subangular to subrounded clasts. Bedding dips in one direction at a moderate angle. Highly oxidized interbeds are present throughout of both iron and manganese. The lower contact is covered.

Interpretation: The low angle planar cross-bedding appears to be fluvial foreset or longitudinal bar beds from an moderate energy fluvial environment. Lack of detail prevents a more accurate interpretation.

Unit 5 (~1 m): Sand and gravel, moderately well sorted beds which truncate the lower unit; the clasts are sub- to well rounded, and no bigger than 3-4 cm a-axis diameter; the bed form is obscured but appears roughly trough cross bedded. The lower contact is abrupt to erosive. (see photos).

Interpretation: Fluvial topset sand and gravel or braided stream environment.

Unit 6 (1-2 m): Horizontally bedded, fine sand and silt. The lower contact is abrupt.

Unit summaries continued...

Interpretation Unit 6: Possibly lacustrine, shallow marine or flood overbank deposit.

Unit 7 (~0.10 m): Poorly sorted sand and gravel with an erosional lower contact.

Interpretation: This unit appears to represent an increase in fluvial activity.

Unit 8 (~3 m): Horizontally bedded, organic rich silt, colour ranges from Munsell 10 YR 3/1, very dark grey to 10 YR 2/1, black. Organics include wood, branches and other plant remains, both intact and broken, compressed and almost lignitized. The organics decrease eastward and are thickest at the centre, and highest portion of the section; they tend to decrease up section (see photo 95-1 #29). (S-37, ^{14}C of wood)

Interpretation: This unit has a combination of detrital and in situ organic material thus most likely represents a low energy bog. The broken fragments of wood and coal suggest a detrital influx of organics and either coal from reworked Cretaceous, Nanaimo sediments or coalification of in situ organics.

Unit 9 (~10m): Sand - coarsening upward sequence of medium to coarse planar cross-bedded sand and rare gravel, showing scour and planar cross-bedding features to top. The basal 2 meters contains clay lenses and rip-ups which are finely laminated and up to 0.02 m thick.(photo R5-5); the average bedding plain of the sand beds is 31° towards 042° towards the northeast; some pebble cross-bedding measured 10° towards 067° the east; the lower contact is generally conformable but with some erosional features.

Interpretation: Low flow regime linguoid to transverse bar deposits cross cut at times by channel fill deposits. The conformable lower contact with rare clay rip-ups suggests a sudden channel shift into an otherwise quiet sedimentary environment.

Unit 10 (~0.5m) Sandy diamicton with 0.05 meter thick lenses of coarse sandy diamicton up to 50 centimeters wide; the lower contact is abrupt and shows flame structures, especially beneath a large boulder found in unit 7.

Interpretation: Sub-aerial debris flow interbedded with proximal fluvial outwash.

Unit 11 (~6m): Sandy diamicton, Munsell 2.5 Y 4/2 dark greyish brown; this mostly massive diamicton is 80-90 per cent matrix, 20-30 per cent clasts; matrix medium to coarse sand, clasts up to 1.5 meters a-axis diameter present throughout (photo R5-6 and 7, of a sub-angular granodiorite clast which sits directly on flamed or deformed sands of unit 6); clasts average 0.02 meters and range from sub-angular to well rounded; clast lithology: 32% mafic volcanic, 18% diorite, 14% siltstone, 13% plagioclase porphyry, 6% granodiorite, 6% quartzite, 6% augite porphyry, 3% sandstone, 2% potassium feldspar. This unit is generally massive but signs of stratification in the form of cobble concentrations and matrix fining and coarsening do exist throughout; the lower contact is erosive or abrupt and uneven (HB92-78/7 on the lithology).

Interpretation: Probably a meltout till, deposited at the glacier's base. The lithology and sub-angular to well rounded nature of the clasts suggest a Vancouver Island and Georgia Basin origin, however, the sandy texture and rare Coast mountain lithologies imply some influence by Cordilleran ice or reworking of Cordilleran deposits.

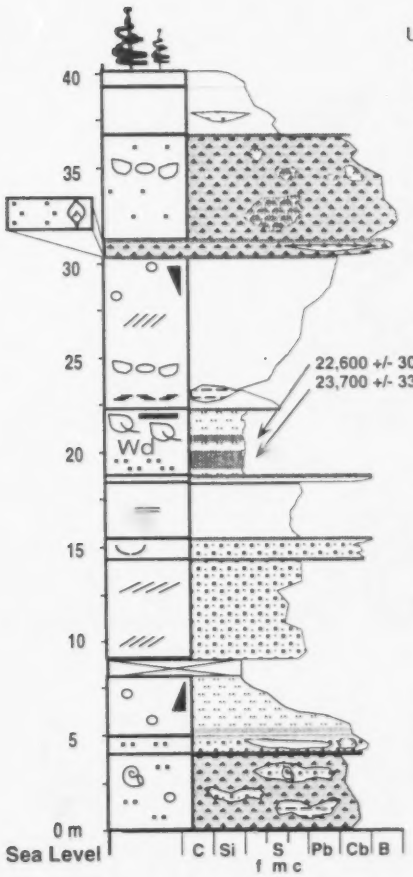
Unit 12 (3-4m): Medium to fine sand, light brown (no Munsell taken) and massive to poorly bedded. This unit also contains rare, well sorted gravel lens. The lower contact is abrupt.

Interpretation: This appears to a fluvial debris flow deposit which has been eroded by scour fills or channel fills.

Unit 13 (~1m): Massive fine to medium sand. The lower contact appears gradual. There are no real details from 1992.

Interpretation: This unit is probably closely associated with unit 9.

THE CORDOVA BAY COMPOSITE SECTION
48°29'40"N, 123°19'25"W



22,600 +/- 300 (GSC 84 Plant Fibres, Dyke et al. 1965, p.34)
23,700 +/- 330 (GSC 2809 Wood)

Unit 13 (~1 m): Massive fine to medium sand

Unit 12 (3-4 m): Medium to fine sand, light brown, massive to poorly bedded, containing rare gravel lenses.

Unit 11 (~6 m): Sandy diamicton dark greyish brown (Munsell 2.5Y 4/2), massive to poorly stratified, 80-90% matrix medium to coarse sand; clasts up to 1.5 m in diameter (granodiorite) and average 0.02 m

Unit 10 (~0.5 m): Sandy diamicton with 0.05 meter lenses of coarser, sandier diamicton

Unit 9 (~10 m): Medium to coarse planar cross-bedded sand and rare gravel, dipping 31° towards 042° to 10° towards 067°

Unit 8 (~3 m): Horizontally bedded, organic rich silt, very dark grey (Munsell 10YR 3/1) to black. Organics decrease up section.

Unit 7 (~0.10 m): Poorly sorted sand and gravel

Unit 6 (1-2 m): Horizontally bedded sand and silt

Unit 5 (~1 m): Sand and gravel, moderately well sorted, clasts sub- to well rounded, roughly trough cross-bedded

Unit 4 (~6 m): Well sorted sand and gravel with sub-angular to sub-rounded clasts.

Unit 3 (2-3 m): Slightly oxidized coarse sand and gravel to blue-grey silt

Unit 2 (1 m): Poorly sorted coarse sand and gravel with rare silt and granite clasts

Unit 1 (~4 m): Silty, blue grey diamicton with pebbles, striated clasts of basalt and diorite. 80% matrix, consisting of 5% clay, 48% silt, 47% fine sand

THE COWICHAN HEAD COMPOSITE SECTION
(48°33'45"N, 123°22'10"W)

Access:

The Cowichan Head section is approximately 15 kilometers north of Victoria on the east side of the Saanich Peninsula. From Victoria the site is reached by driving north on highway 17 (the Pat Bay Highway) approximately 14 kilometers and then heading eastward on the Island View Beach road up to the parking lot. From the parking lot the section is located a mere fifteen minute walk southward along the beach [or a twenty minute swim at high tide].

Geomorphology:

As you leave the highway on Island View Beach Road you are at the bottom of a flat, broad valley underlain by thick, clay rich diamicton and bounded by two low ridges running parallel to the coast. These low ridges are the second and third in a series of five ridges which begin at Keating Cross Roads, west of Highway 17. The fourth ridge is James Island which can be viewed from Island View Beach as a cross-cut and exposed drumlin (fig 5). The fifth ridge can be seen just beyond James Island. It forms the pale, sandy cliff on the west side of Sidney Island.

Unit Summaries: The Cowichan Head Section - HB92-2, HB92-18, HB92-114, HB93-118, 119, 120 and HB93-122; see photos R1 22-24, and R7 12-17.

The present day beach: The southern end of the Cowichan Head section is composed of near horizontal clays and silts with numerous erratic boulders cobbles and pebbles from cliff erosion; numerous shells and bioturbation detritus and rare inclusions of wood from waterlogged beach debris. *[Note: this is very similar to Unit 3 and is probably a lower portion of unit 3].*

Unit 1 (0-5 m): A coarsening upward sequence of dark grey to light grey (no Munsell taken) clay to silt to fine sand; horizontally to sub-horizontally bedded situated approximately 2 meters above maximum high tide level; contained within this unit are 0.2-0.5 meter interbeds of poorly sorted pebbly silt and clay; the pebbles and rare cobbles within these interbeds are well to sub-rounded basalts, siltstones and diorites; the lower contact is covered by ~2 meters of slump material.

Interpretation: The horizontal to subhorizontal clay, silt and fine sand suggests a low energy, subaqueous environment; either lacustrine or marine. The interbeds of poorly sorted pebbly silt and clay with rare cobbles implies either slump deposition or glacial melt out and drop stone material. This unit 1 has been assigned to the Pre-Wisconsinan Muir Point Formation by Hicock (1980). The lower contact is covered by the modern beach.

Unit 2 (0-1.5 m): Gently dipping, planar cross-bedded, sand and gravel The lower contact is erosive.

Interpretation: This unit may represent anything from a beach deposit to a longitudinal bar to a deltaic front. There are too few details to narrow this interpretation down. *Unit 2 is thought to be part of the Muir Point Formation (Hicock, 1980).*

Unit 3 (0-4 m): Shell-rich bluish (Munsell 7.5 YR 4/0 moist), silty sand with mud and clay stringers and sediment filled intersecting tubes; and rare pebbles throughout; this unit shows very poor bedding if any in most places; it is 95 per cent matrix - 36 per cent silt, 18 per cent clay and 46 per cent sand (see sample HB92 S67/3 for texture) with rare clasts are from 0.8 cm to a maximum a-axis diameter of 5 centimeters, sub-rounded to sub-angular, some clasts are covered with barnacle marks (see sample HB94-S02); the lower contact is erosional.

Interpretation: The fine texture and poor bedding of this unit combined with the barnacle marks and bioturbation imply a marine depositional environment. The intersecting, sediment filled tubes and shells suggest bioturbation; the rare cobbles and pebbles throughout may have been deposited as beach lag, similar to the modern beach environment in this area, or they may have been deposited as dropstones from a calving ice front. Radiocarbon dates from numerous marine shells (~35 000 years before present +/- 1600 years L-514D) and wood dated >42 000 (L-514C) and >51 000 years before present (GSC-94-2) (Fulton and Halstead, 1972; Olson and Broecker, 1959). These dates imply a Middle Wisconsinan age but are at the farthest extent of radiocarbon dating. Fossil barnacles (Balanus glandula) collected from the upper 2.5 meters of this unit indicate cool to temperate conditions (Alley, 1979).

Unit 4 (10-12 m): Oxidized fine to coarse sand with minor, discontinuous interbeds of horizontally bedded gravel; the planar cross-beds dip from 2-25° from base to top and dip and fine towards the south. The lower contact is abrupt.

Unit summaries continued...

Interpretation: The planar cross beds which dip from 2 to 25° up section, suggest an advancing source fluvial source of moderate flow regime. The more horizontal nature of these beds in a southerly direction suggests a northerly source suggesting foreset beds from a prograding deltaic environment. The oxidized nature of this unit may be a result of sub-aerial exposure or may be from post deposition weathering. The minor gravel beds could either represent broad channels across the deltaic front or periods of higher fluvial discharge. *[Unit 4 is thought to be the lower member of what Armstrong and Clague (1977) identify as the Cowichan Head Formation.]* Apparently contains sand casts of marine worms. (Armstrong and Clague 1977).

Unit 5 (3-5 m): Organic rich silt with interbeds of sand. This unit contains an extensive oxidized organic rich unit from which plant fragments have been radiocarbon dated (Dyck et. al. 1965) at 35,600 + 3000, -2200 y BP). The upper meter contains flame and pillow structures, while the lower contact is gradual.

Interpretation: This unit may represent a backswamp or estuarine environment. The organic material is fragmented and thus probably detrital. The extensive organic layer at the base of this unit appears to be a paleosol. The deformed upper contact with unit 6 suggests its relatively rapid deposition over unit 5.

Note: Units 4 and 5 form the type section for the Cowichan Head section, introduced by Clague 1976 and defined by Armstrong and Clague 1977. It represents the Olympia non-glacial interval which followed the penultimate or pre-Fraser glaciation (represented by Dashwood drift on Vancouver Island) (Armstrong and Clague 1977).

Unit 6 (20-30 m) Coarsening upwards; slightly oxidized horizontal to trough cross-bedded sand and gravel with pebble concentrations in the troughs; flame structures can be found at the base of this unit. The lower contact is abrupt and the unit thickens towards the south.

Interpretation: This unit appears to represent subaqueous to sub-aerial fluvial channelization associated with deltaic topset beds. The coarsening upward nature of this deposit suggests a prograding environment. The deformational structures at the base of this unit are probably from sudden channel shifts and bed load changes. *[Pollen assemblages (Fyles, 1963 and Clague, 1977) show this unit to have been deposited in an environment cooler than today.]*

Unit 7 (2-5 m) Greyish-brown (no Munsell) sandy diamicton; matrix supported, matrix 80-85 per cent, clasts 15-20 per cent; matrix approximately 5 per cent silt and fine sand, 60 per cent medium sand, and 35 per cent coarse sand and granules; clasts mostly rounded to sub-rounded with rare sub-angular clasts; the lower contact is erosive and unconformable. The fabric is somewhat mixed but dips range from 3-51° averaging 19° and trend roughly south-south west. The lithology is: Basalt 26 per cent, fine green volcanics 16 per cent, sandstone 14 per cent, diorite 14 per cent, plagioclase porphyry 12 per cent, siltstone 6 per cent, quartz and chert 4 per cent each, and granite and gneiss comprise approximately 2 per cent each.

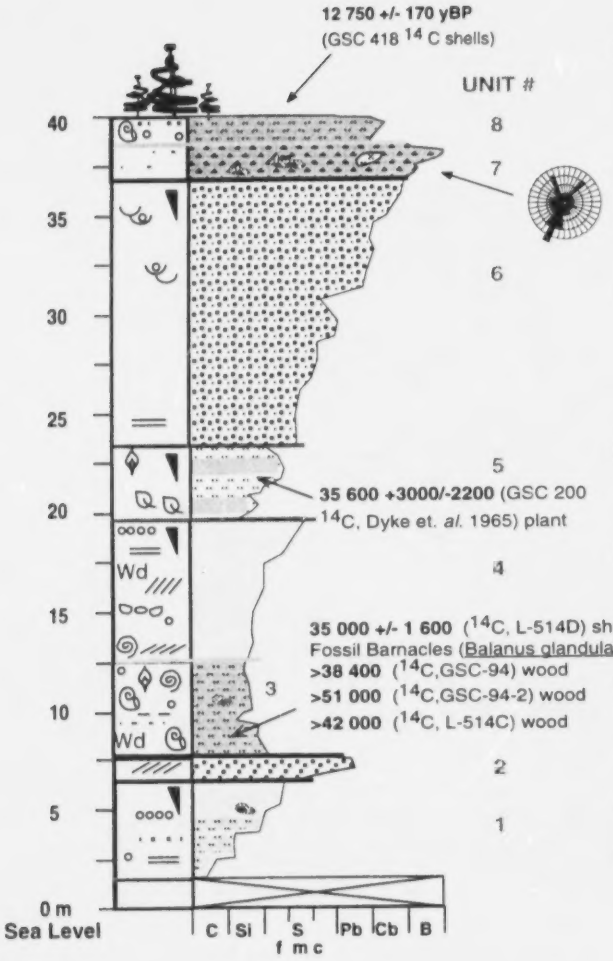
Interpretation: The steeply dipping fabric and lack of fines implies a debris flow origin, however, the lithology and lack of upland source suggests that this unit probably had a glacial origin. The lithology has predominantly local origin with abundant Vancouver Island volcanic and few Coast Mountain rocks (i.e.. gneiss, schists and granites).

NOTE: In some locations this diamicton appears more silty than in others (i.e. in the valley approaching Cowichan Head).

Unit 8 (0 to ~2m): This unit is composed of thin, discontinuous brown clays with numerous pebble inclusions [Locally called Victoria clay], and is dated as no younger than 12 750 +/- 170 (GSC - 418) years before present (from marine shells in an overlying sand unit - Dyck et. al., 1966). The lower contact appears gradual to sharp.

Interpretation: This unit appears to have a glacio-marine origin and is probably the result of sub-marine deposition of clays and dropstones on a isostatically depressed landscape during the receding phase of the Fraser glaciation.

COMPOSITE COWICHAN HEAD SECTION
48°33'45"N 123°22'10"W



Unit 8 (0-2 m): Discontinuous, clay rich, brown diamicton. Dated at no younger than 12 750 +/- 170 Bp (GSC-418) from overlying marine shells (Dyke et. al., 1966)

Unit 7 (2-5 m): Greyish brown (no Munsell) sandy diamicton. The fabric dips approximatley 17° towards 206°.

Unit 6 (20-30 m): Slightly oxidized horizontal to trough cross-bedded sand and gravel. The unit thickens towards the south.

Unit 5 (3-5 m): Organic rich silt with interbeds of sand. This unit contains an oxidized, organic rich bed near its base

Unit 4 (10-12 m): Oxidized, fine to coarse sand with minor discontinuous, horizontal interbeds of gravel; planar cross-beds dip southward from 2-25° from base to top

Unit 3 (0-4 m): A poorly bedded to massive, shell rich, bluish-grey (Munsell 7.5YR 4/0) silty sand; containing rare pebbles, shells and wood throughout

Unit 2 (0-12 m): Gently dipping planar cross-bedded sand and gravel

Unit 1 (~0-10 m): Clay to fine sand; dark to light grey, coarsening upward, horizontally bedded with rare interbeds of pebbley silt and clay

THE HEAL LAKE SECTION
(48°32'25"N, 123°27'50"W)

Access: This section is located within the bounds of the Hartland Road Dump ~20 kilometers northwest of Victoria, British Columbia.

Geomorphology: The Heal Lake section is actually a rare glimpse of the contents of a present day, lake bottom. This natural bedrock basin was drained in 1992 to extend the capacity and life-span of the Hartland Road landfill and its exposure shed some light on the post-glacial history of southeastern Vancouver Island. Its location within the hummocky bedrock terrain of Lower Paleozoic Wark Gneiss (Muller 1980) which appears to have been scoured clean during glacial periods as seen by its striated bedrock walls, however, this same impermeable terrain acted as a catch-all basin throughout post-glacial time. Heal Lake is ~128m above sea level. Maximum marine limit in the area was 75m above present sea level (Howes and Nasmith, 1983).

Composite Section: HB92-83 and 84
Unit Summaries: The Heal Lake Section see Photo R5-25

Bedrock (0-40m) Gneissic bedrock rounded and striated at approximately 023°

Interpretation: Bedrock of the Lower Paleozoic Wark Gneiss (Muller 1980).

Unit 1 (0-0.8m): Diamicton, grey (7.5 YR 5/0), clay rich to sandy at top. It is composed of approximately 30 per cent clasts and 70 per cent matrix, however, the clast content and size increases up section. Clast fabric shows a 14° dip towards the centre of the lake basin. Clasts are mostly subrounded to rounded, average about 0.5-1 cm a-axis diameter but have a maximum diameter of ~15 cm. The matrix consists of approximately 30 per cent silt and clay, 40 per cent fine and medium sand and 20-30 per cent coarse sand and pebbles (hand textured) - Sedigraph results of HB92-S44 show clay at 4%, silt 27% and sand at 69%. The diamicton is unconsolidated enough that it liquefies when squeezed. The lower contact is covered.

Interpretation: The unit's lack of compaction and down slope fabric suggest a debris flow origin, however, the high concentration of fines, the lack of organics and the direct contact on striated bedrock suggests a glacial origin.

Unit 2 (~0.18-0.05m): Sand - Well sorted fine to coarse texture. It is a very dark grey (5Y 3/1) sand with minor organic partings towards the basin and an increasing organic content towards the unit's top; this organic material is partly broken but to a great extent retains its original form and texture. The bedding is poor to sub-horizontal and the unit contains rare lenses of subrounded cobbles. The cobbles range in size from 2 to 12 cm a-axis diameter . The lower contact is sharp and erosional.

Interpretation: The well sorted nature of this unit combined with the rare lenses of subrounded cobbles suggest and organic partings indicate a moderate to low energy fluvial environment with rare flooding events or channel shifts The increasing organic content up section and its mostly intact nature implies both in situ deposition and an increasingly productive climatic. Wood from within this unit was dated at 12,840 +/- 80 yBP (Beta 60553, Hebda pers. comm. 1995).

Unit 3 (0.06-0.09m): Silty organic gyttja: Approximately 98 per cent organics and 2 per cent silt and clay, this dark brown (7.5 YR 3/2) material is full of broken twigs, lodge pole pine cones, bark and needles. It is very moist and holds finger prints when squeezed. The lower contact is sharp but appears to be conformable with the organic rich sands of unit 3. A lateral continuation of this unit 30 meters towards the basin shows a decrease in organics and an increase in clay, silt and sand.

Interpretation: This material appears to be from a low energy sub-aqueous to sub-aerial environment. The lack of in situ trees or roots combined with the plentiful conifer cones, bark, needles and broken twigs, implies an environment which is near to a very productive source but influenced by low energy fluvial action. The associated clays, silts and sands towards the basin bottom indicate a low energy fluvial to lacustrine environment probably similar to the modern lake environment.

Unit 4 (0.01m): Sand - Fine to medium grain size, light grey (10 YR 7/1) and very well sorted. It has a very rough hand texture and has a high contrasting colour compared to the surrounding sources. It is discontinuously dispersed and poorly horizontally bedded over most of Unit 3. The bedding dips down slope toward the basin's bottom at both sections. The lower contact is sharp.

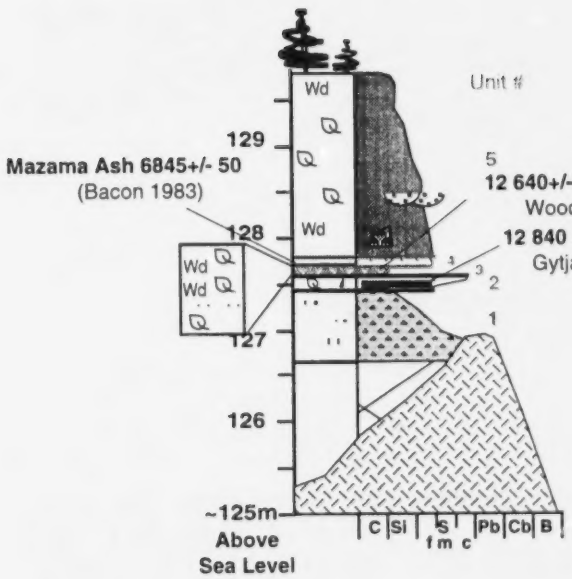
Interpretation: Its colour, sorting and placement combined with a lack of a local source material suggests this an ash. The only ash known to have reached this area of Vancouver Island is the Mazama ash from the 6845 +/- 50 y BP (Bacon 1983) eruption of Mount Mazama (Clague *et al.*, 1995). The age and type of ash was confirmed by Hebda pers. comm. 1995).

Unit summaries continued...

Unit 5 (~2.50m): Peat and gyttja with abundant tree trunks and branches - Dark reddish brown (5.5 YR 2.5/2) ; tree trunks in this unit are more than 20 centimeters in diameter and retained much of their original bark; 5 cm thick, trough shaped, sand and gravel lenses, were found, some up to 1 meter across, these lenses contain well sorted and rounded sands as well as rare angular clasts as large as 5 centimeters at maximum a-axis diameter of local gneissic lithology. The unit dips down slope in the direction of the basin bottom and its lower contact is sharp but apparently conformable.

Interpretation: This material may have been formed in situ, as organic material grown and deposited in a low energy sub-aqueous and low to anoxic environment, such as a bog, lake or fen, however, the rare gravel lenses suggest a fluvial influence and rare flooding events. Angular, local clasts and large in situ tree trunks suggest a basin of accumulation where colluvium and organic detritus built up between the horizons of low energy fluvial deposits. The angular nature of the clasts may have been a result of freeze-thaw cycles as there is a lack of source for gravity broken clasts. According to research done by Richard Hebda the tree remains were from Douglas Fir, Lodge pole Pine and Red Cedars (Richard Hebda, per. comm. August 12, 1992).

COMPOSITE HEAL LAKE SECTION
48°32'25"N 123°27'50"W



Unit 5 (2.5 m): Peat and gytja, with abundant tree trunks and rare angular local clasts

Unit 4 (0.01 m): Sand, light grey (10YR 7/1)
Mazama Ash
Max. age 6390 +/- 160 BP (GSC 963 Gyttja)
Min. age 6670 +/- 120 BP (I-3674 Gyttja)

Unit 3 (0.06-0.09 m): Gytja, silty

Unit 2 (~0.05-0.18 m): Sand, organic rich

Unit 1 (0-0.8 m): Diamicton, grey, unconsolidated; the sedograph shows that the matrix is 4% clay, 27% silt and 69% sand

Bedrock (~0-40m): Gneissic Bedrock striated at 023°

THE METCHOSIN GRAVEL PIT SECTION
(48°24'45"N, 123°29'10"W)

Access: This section is located approximately ten kilometers west of Victoria and can be accessed by taking the #1 Highway to Colwood; the #14 Highway to Metchosin Road and driving approximately three kilometers to the Metchosin gravel pit.

Unit Summaries:
Refer to Figure 1: The Metchosin Gravel Pit Section
Note: The base of this pit is 7 m. above a diamicton (Ed Freund, manager, per. com.).

Composite section description of HB92 103-106

Bedrock (0-3m): Bedrock (Amygdaloidal basalt) shaped by ice; only appears on the western side of the pit; striated and smoothed [rat tail]; striae 'mold' along the long axis of this tear dropped shaped outcrop at 022°; the bedrock is rounded toward 022° and pointed toward 202° [This stoss and lee feature denotes a northerly source). (Photo R6-22-24)

Interpretation: Metchosin volcanic complex. Pillow and flow basalt, breccia and tuff; Tertiary in age (Muller 1980). This bedrock is well striated and shaped by a south-southwesterly ice flow as seen by stoss and lee features.

Unit 1 (0-2.5m): Silty diamicton; (photo R6-23); Moderately indurated and matrix supported; Matrix 85 per cent, Clast content ~15 per cent - Matrix: 2-5 per cent clay, 30 per cent silt, 30-40 per cent fine sand, 20 per cent medium sand, and 5-10 per cent coarse sand. Clasts: mostly well to sub-rounded, fewer than 5 per cent sub-angular in shape; Average clast size 2 - 3 centimeters a-axis diameter, maximum clast size ~30 centimeters a-axis diameter. The clasts are comprised of ~50 per cent mafic volcanics, (including about 20% plagioclase porphyry), 20 per cent diorite, 10-15 per cent siltstone, 5-10 per cent gneiss, 5-10 per cent felsic intrusives and minor chert. Fabric taken from this unit (S1 = 0.7; V1 = 037°, 14°; N = 25) denotes a southwesterly paleoflow. Sample for texture is HB92-57-1 and for lithology is HB92-104/1. The lower contact is erosive.

Interpretation: A strong a-axis fabric of ~037°, 14° north combined this unit's massive and silty nature suggests a basely derived lodgment and melt out origin. Lithology suggests a Georgia Basin and Coast mountain influence on mostly Vancouver Island material.

Unit 2 (0-0.07 m): Interbedded fine silt and clay (clay 10-15%; silt 90-95%; hand textured), Finely laminated and planar cross-bedded and dipping 09° towards 076°. The unit has a maximum thickness of 5 to 7 centimeters and is an olive brown colour (Munsell 2.5Y 4/4 moist). The upper 2 centimeters are disturbed by the overlying gravel. The lower contact is covered.

Interpretation: This gently dipping silt and sand unit appears to be low flow regime bottomset to foreset beds.

Unit 3 (2.5 to ~17 m): Large scale, planar cross-bedded, interbedded gravel and cobbly gravel with apparent dips of up to 25° towards the south-southwest. These gravels are interbedded with sub-horizontal medium to coarse sands. Sand beds thin from ~35 centimeters at the base to a maximum of 10 centimeters at the top The gravel beds increase in frequency and thickness towards the top, i.e. their maximum thickness at the base is ~30 centimeters while at the top of the unit it is up to 2 meters in thickness. The coarsest gravels are openwork and usually manganese stained. All clasts are well rounded with only rare sub-angular clasts; There are a wide variety of clast lithologies. The lower contact is gradational, generally conformable but rarely erosional.
Note: Bedding becomes finer and more horizontal, at the same elevation, when looking southward; beds also appear more lenticular when viewed toward the south.

Interpretation Unit 3: These steeply dipping well graded sand and gravel is typical of subaqueous sediment gravity-flow deposits in river-dominated prograding delta foresets (Bhattacharya and Walker, 1992). The coarsening upward and steepening nature of the beds indicate a distal lower-slope to proximal upper-slope deltaic facies change.

Unit 4 (~2m): A fining upward sequence of gradational to erosive, trough cross-bedded sand and gravel; with the rounded to sub-rounded coarse clast fragment. The lower contact is erosive.

Interpretation: Minor channel fills probably associated with top-set bedding in a deltaic environment.

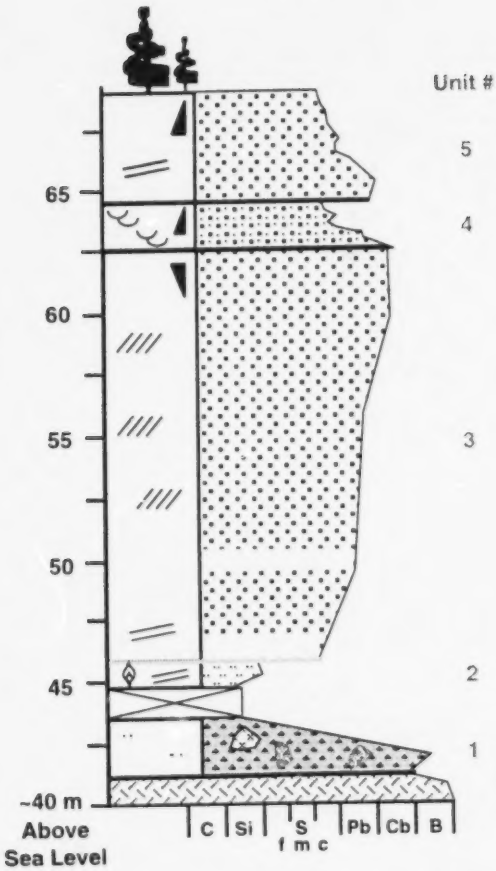
Unit summaries continued...

Unit 5 (4-5m): Moderately sorted fining upward sequence of sub-horizontally to horizontally bedded cobbly gravel; Average clast size 3-10 centimeters, maximum clast size 40-50 centimeters (a-axis diameter); The large clast fragment is matrix supported, however, well sorted 2-3 centimeters gravels are openwork; Lower contact erosional. (photos R6 26-28).

Interpretation 5: This unit appears to be a topset channel deposit whose scoured, lower contact and upwardly fining nature indicate channel shifting and abandonment. The upper meter of this unit is pedogenically altered [regosol to brunisol see notes].

THE METCHOSIN GRAVEL PIT SECTION

48°24'45"N 123°29'10"W



Unit 5 (4-5 m) : Cobbly gravel

Unit 4 (~2 m) : Sand and gravel

Unit 3 (2.5-17 m) : Interbedded pebbly and cobbly gravel; rare sand interbeds at the base; the planar cross-beds dip ~25° towards the south-southwest

Unit 2 (0-0.07 m) : Silt and clay, interbedded; bedding dips ~09° towards 076°

Unit 1 (0-2.5 m) : Silty diamicton; moderately indurated, strong fabric dips 14° towards 037°.

Bedrock (0-3 m) : Amigdaloidal basalt; striated and fluted at 22° towards 202°

THE MUIR POINT COMPOSITE SECTION
(48°21'25"N,123°45'00"W)

Access:
The Muir Point section is located approximately 31 kilometers west-southwest of Victoria, British Columbia. It is reached by driving just west of the town of Sooke, turning south onto Whiffin Spit Road and then westward directly onto McMillan Road. Easy access and a good look at the upper section was provided via a private path at 7281 McMillan Road and the main section can be found approximately one kilometer westward along the beach.

Geomorphology:
The topography of the 40 meter cliffs that make up the Muir Point section is expressed by kilometer long, northeasterly trending morainal ridges.

Unit Summaries: from sections HB92-57 and HB93-121; Refer to Figure 1: The Muir Point Section

Unit 1 (0-1.5 m) Lower Diamicton: Greyish brown (no Munsell colour), moderately indurated, and approximately 65 per cent matrix supported; the matrix is approximately 5-10% silt and fine sand, 70-80% medium sand and approximately 10-15% coarse sand and granules (hand textured). Clasts are striated, average approximately 3-5 cm a-axis diameter to a maximum of 90 cm a-axis diameter; clast lithology consists of more than 50% mafic volcanic clasts, about 27% dioritic clasts and fewer sedimentary and granitic clasts (figure 17). The fabric trends northwest to southeast with a moderate southeast plunge. The lower contact is covered. Note: Units 1 and 2 are best exposed 200 meters east of the path from 7281 McMillan Road.

Interpretation: The moderate induration, striated clasts and strong northwesterly trending fabric indicate a probable sub-glacial origin. The clast lithology indicates local sources with a minor influence from either coast mountain ice or a re-entrenchment of previously deposited mainland sediments.

Unit 2 (0-1m) Gravel: Red, iron oxidized and cemented, trough-cross-bedded gravel with organic rich silt and limonite casts of branches (Hicock 1993). It is matrix supported some open work lenses, the matrix consists of medium to coarse sand and lesser silt (percentages vary between beds). Clasts range from granules to large cobbles and are sub- to well rounded. This unit is best exposed 200 meters east of the path from 7281 McMillan Road at low tide but is also found at the base of the main section approximately one kilometer west of the 7281 path. The lower contact is sharp.

Interpretation: The well rounded and sorted clasts have a fluvial origin. The trough cross-bedding and wide range of clast sizes indicates a high bed load environment with a shifting channel, most often associated with a braided rivers. The organic rich silt layers and limonitic casts of branches (Hicock 1993) suggests deposition in overbank stages.

Unit 3 (~3 m) Silt, Sand and Gravel: The sub-horizontally, interbedded silt and sand unit contains a few gravel lenses. Clasts within this unit are well to sub-rounded and well sorted. The unit contains abundant organic detritus and plant fragments which increase in concentration up section. The lower contact is erosional.

Interpretation - Unit 3: The organic rich silt and sand suggests a low energy bog or flood plain environment; sand and rare gravel lenses suggest gentle fluvial action punctuated by periodic channel shifts as may be found in estuarine or flood plain environments. Fragmented plant remains indicate a detrital origin; and high organic content suggests either low decay rates or a high influx rates. Rare marine dinoflagellate cysts, described by Alley and Hicock (1986), show a minor marine influence suggesting estuarine origin.

Unit 4 (~1.5 m) Silty Peat: This unit grades from a silty peat at its western end to a peat rich silt and sand at its eastern end; plant remains are mostly intact, however plant fragments appear, to a lesser degree, up the unit. Wood from within this unit has been dated at >40,000 years BP (I-8449, wood)(Hicock 1993). The lower contact is gradational.

Interpretation: The autochthonous peat would imply a bog or marshland environment; increasing amounts of silt and sand at the eastern end of the unit suggests close proximity to a low energy, flood plain or lacustrine environment.

Unit 5 (~15m) Gravel: Moderately well sorted, interbedded gravel and sandy gravel containing large lenses of both coarse gravel and some sandy diamicton; clasts are sub-rounded to rounded. The lower contact is abrupt.

Interpretation Unit 5: The sandy gravel with large lenses of coarse gravel appears to be from a fluvial environment undergoing large scale channel shifts; this may be a product of a meandering river channel or a large scale braided channel. The discontinuous sandy nature of the diamicton lenses, combined with their lack of striated clasts suggest a debris flow origin. Hicock (1993) noted a lack of

Unit summaries continued...

pollen in this unit which, in concert with the coarser clast content, debris flow features, and the lack of organics suggests a cooler, moister climate trend.

Unit 6 (0-5m) Silt, Sand and Gravel: Organic rich, horizontally interbedded silt, sand and gravel with organics that decrease up section; clasts are well sorted and rounded and appear no greater than 2 to 3 cm a-axis diameter. A radiocarbon date of 43 600 +/- 660 years BP was obtained on wood from this unit by Alley and Hicock (1986) (GSC-3295 wood). The lower contact is sharp and appears to be unconformable.

Interpretation: The horizontally bedded silt, sand and gravel indicates a changing flow regime that may be associated with climatic fluctuations or variations in sub-aqueous to sub-aerial flow, as can be found in near shore environments; the abundant plant macro fossils and pollen, found in the lower 2m of this unit by Alley and Hicock (1986), show a climate cooler and moister than ours present climate (Alley and Hicock 1986) but apparently warmer than that of unit 5.

Unit 7 (0-2m) Middle Diamicton: Grey (7.5 YR 5/0), highly indurated, poorly sorted and matrix supported diamicton; the matrix consists of 2-5% clay, 10-20% silt and approximately 74% fine to coarse sand. Clasts are well striated, rounded to sub-rounded with rare, basaltic, sub-angular boulders (up to 100 cm a-axis diameter); the average clast size, however, is 2-3 cm, a-axis diameter; clast lithology is 43% mafic volcanic, 25% diorite, 9% granite, 9% plagioclase porphyry and less abundant amounts of quartzite and sedimentary clasts (see HB92-S15). Two well preserved branches (see **fig**ure 1), with very little bark remaining, were found in the middle of this unit and have been conventionally radiocarbon dated at 40 800 +/- 2600 and 40 800 +/- 3400 years BP (AECV #1869C and AECV #1868C, respectively). The entire unit shows signs of deformation in the form of parallel cracks that dip 30-55° towards 320°. The lower contact is covered, however, its eastern edge appears to unconformably truncate units 2 and 3.

Interpretation: The indurated nature of this unit combined with poor sorting and abundant striated clasts suggests it is probably of sub-glacial origin. The lithology and fabric indicate a provenance from both Vancouver Island and the Coast Mountains. Fabric and parallel cracking, most likely tension crack structures, suggest a northwesterly ice flow and a sub-glacial origin. Radiocarbon dates imply either one of two scenarios: 1) this till was deposited between 37 400 and 44 200 BP, during an ice advance which picked up local, in situ, vegetation; or 2) a late Quaternary glaciation (*i.e.* Fraser) entrenched previously deposited and older organic material, possibly such as found in unit 6. Note: It should be noted that dates from wood within this unit, although replicated and finite, are both near the limit of conventional radiocarbon dating.

Unit 8 (~0.2m) Silt, Sand and Gravel: A continuous sub-horizontally interbedded unit of fine silt, sand and gravel. Beds are moderately well sorted; clasts are sub-rounded to well rounded and no greater than 2 cm a-axis diameter. The lower contact is sharp but conformable.

Interpretation: This is a fluvial deposit whose continuous nature, relatively small clast size and sub-horizontal bedding suggest a low flow, braided stream or top-set deltaic environment. However, its conformable position between two large diamicton deposits suggests it may be a sub-glacial fluvial deposit.

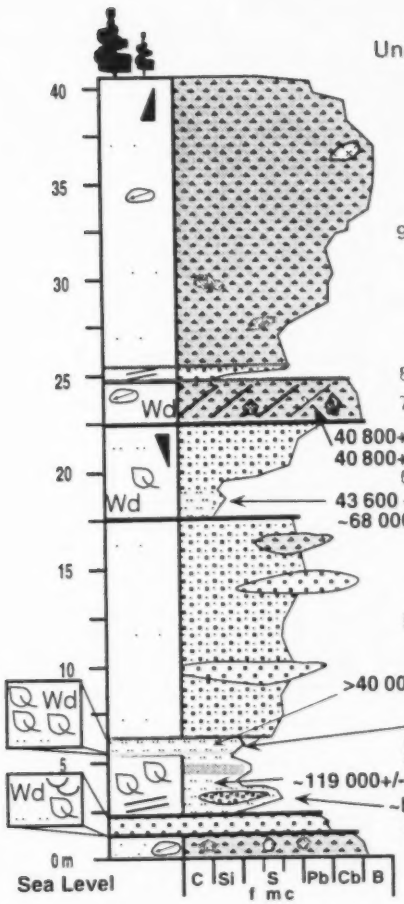
Unit 9 (3-6m) Upper Diamicton: This is a greyish brown (no Munsell taken), well indurated, sandy diamicton; it is Matrix supported with 60-70% matrix, 30-40% clasts, the matrix consists of approximately 5-15% silt and fine sand, 30-40% medium sand, 30-40% coarse sand and 10% granules and small pebbles (hand textured). Clasts average 2 cm a-axis diameter but may be found as large as 1 meter a-axis diameter; rare striated clasts are present; clasts are mostly sub- to well rounded. The clast lithology is 24% mafic volcanic, 22% sedimentary, 19% diorite, 16% granite, 12% quartzite and minor plagioclase porphyry and gneissic components. The fabric shows a general northwestward trend and a relatively steep dip (averaging approximately 19° and ranges from 2° to 37°). This unit tends to fine up section (i.e. fewer boulders and more pebbles). The lower contact unconformably truncates units 3-6 but sits conformably on unit 7.

Interpretation: A lack of fines (i.e. clay) and a steeply dipping fabric indicates some reworking of material. However, a fairly consistent fabric and well dispersed striated boulders, shows signs of en glacial ice movement. Its lower contact is sharp and though it erodes through units 3 to 6 it appears to sit on unit 8 in a flat lying, apparently conformable manner. It was most likely deposited in the late Quaternary (i.e. Fraser) glaciation.

Note: Hicock and Dreimanis (1985) used glaciotectonic features and boulder striae, to show that the middle and upper tills at Muir Point flowed in a northwesterly direction. They also indicated that clast lithologies from these two tills have a southeastern Vancouver Island and Coast mountain provenance (Hicock and Dreimanis 1985), suggesting the source of this till may have been from the Coast mountains and Strait of Georgia rather than Vancouver Island.

THE COMPOSITE MUIR POINT SECTION

48°21'25"N 123°45'00"W



Unit 9 (3-35 m) Upper Diamicton: Well indurated with a relatively steeply dipping, northwesterly trending fabric

Unit 8 (~0.2 m) Silt, Sand & Gravel: Interbedded, subhorizontal fine silt, sand and gravel which appears to be conformableyet in abrupt contact with unit 7

Unit 7 (0-2 m) Middle Diamicton: Indurated grey (7.5YR 5/0) diamicton with rare wood, striated clasts and parallel cracks which dip 30-50° towards 320°

Unit 6 (0-5 m) Silt, Sand & Gravel: Organic rich and horizontally interbedded

Unit 5 (~15 m) Gravel: Sandy, with largelenses of coarse gravel and rare diamicton pockets

Unit 4 (~1.5 m) Silty Peat: Autochthonous

Unit 3 (~3 m) Silt, Sand & Gravel: Abundant peat and wood beds and rare gravel lenses

Unit 2 (0-1 m) Gravel: Iron oxidized and cemented with trough cross bedded

Unit 1 (~0-1.5 m) Lower Diamicton: Greyish brown sandy diamicton with striated clasts and a fabric indicating ice flow towards the northwest

THE NORTH SAANICH GRAVEL PIT SECTION
(48°39'25"N, 123°26'00"W)

Access: Accessible via Mills Road just north of the Victoria International Airport. The section is best exposed on the southwest side of the pit.

Geomorphology: The topography surrounding this section is gently rolling to almost level towards the south and east and increasingly hilly and bedrock controlled towards the north. Approximately two kilometers east of the gravel pit is the town of Sidney and the Straight of Georgia, and less than one kilometer west lies the Saanich Inlet. The top of the section is approximately 22 meters above sea level and was most likely submerged at some time since the last Glaciation.

Composite Section HB92-69
Unit Summaries: Refer to Figure 3.12: The North Saanich Gravel Pit Section

Unit 1 (0-0.7m): Interbedded medium and coarse sand; its colour is Munsell 5Y 4/1 moist or dark grey; at the base the unit contains pebbly trough cross-bedded sand with rare rounded to sub-rounded pebbles within the troughs. Finer textured, planar cross-bedding sand occurs up section. The beds have an apparent dip of 12° towards the southeast. From 50 to 70 centimeters the medium and coarse sand becomes extremely well sorted and horizontally bedded; the lower contact is covered but according to gravel pit foremen George Hartshorn and Jim Beaucotte these sands continue down for up to 23 meters.

Interpretation: The planar and trough cross-bedded well sorted and rounded sands suggest a subaerial to subaqueous flood plain to deltaic depositional environment. The fining upward and trough to horizontal bedding sequence combined with the better sorting, suggests a marine or lacustrine incursion and possibly a decrease in fluvial energy. The apparent dip of planar cross-bedded sands may indicate a fluvial source from the northwest i.e. from the Cowichan Valley.

Unit 2 (0.5-7m): Silty diamicton; Munsell colour 5Y 5/3 moist, or olive; matrix varies from 60 to 80 percent and clasts 20-40 per cent; matrix: 5-10% clay, 20-30% silt, 20-35% fine sand and ~25% medium to coarse sand (Hand textured) Sample #HB92-S28 for a sedigraph comparison shows: clay 4%, silt 17% and sand 78%; there is an up section fining to the matrix as it becomes more clay rich towards the top. Clasts: mostly sub- to well-rounded and rarely sub-angular; the average clast size is approximately 0.1 meters, the maximum clast size is up to 3 meters however most large clasts are around 0.5 meters a-axis diameter and these tend to be concentrated at the base of the unit; rare clay rich rip-ups are also located at the base of this unit (see Photo R4-16); Clast lithology: 27% mafic volcanic, 22% plagioclase porphyry, 21% diorite with xenoliths, 12% sandstone, 6% siltstone, 6% granodiorite, 4% pyroxene/hornblende porphyry, 1% pink quartzite and 1% fine conglomerate. This unit is moderately well indurated i.e.. breaks easily with a pick but is rather difficult to crush by hand. The lower contact is abrupt, undulating and erosional.

Interpretation: The high clay content, induration and extremely large clast size without apparent source implies a glacial origin, however, the lack of striated clasts or fluting between the lower sand and this unit. Basal clay rip-ups indicate ice or debris flow movement over subaqueous deposits and the concentration of large clasts at the base of this unit may indicate some sorting. This unit may represent a subaqueous debris flow of glacial material.

Unit 3 (1.6m): Diamicton, clay rich: 90-95 per cent matrix and 5-10 per cent clasts. Matrix consists of 16% clay, 23% silt and 61% sand (Sedigraph sample HB92 S29). Clasts - average size is 0.5 to 1.0 centimeters, maximum a-axis diameter ~10 centimeters; clasts mostly sub-rounded but rarely sub-angular; lithology similar to unit 2; the unit has a blocky structure and iron and manganese staining is present along fractures and is moderately indurated. The lower contact is gradual.

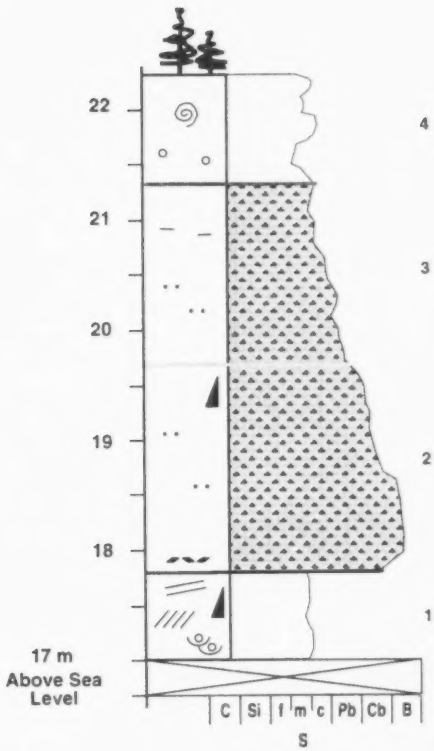
Interpretation Unit 3: This unit appears to be a continuation of Unit 2. The increased clay content is most likely a result of a lesser influence of the lower sands and a greater influence from subaqueous deposits. The induration may be a result of a subglacial origin.

Unit 4 (~1.0m): Sand - moderately well sorted but massive, medium to coarse grained - oxidized in a mottled pattern; moderately indurated; rare weathered clasts exist at the base of this unit (~0.04m maximum a-axis diameter) none exist at the top; the lower contact is abrupt and undulating. Sandy brunisolic soil.

Interpretation: This unit appears to represents a period of subaqueous fluvial deposition. The sand is reasonably well sorted, as if by water, but poorly bedded suggesting that the material was reworked or deposited very quickly. The coarse clasts at the base of the unit do not appear in channel scours or bed forms of any sort but may be dropstones from ice bergs or reincorporated clasts from lower diamictons.

NORTH SAANICH GRAVEL PIT

48°39'25"N 123°26'00"W



Unit 4: Sand - massive, poorly consolidated, oxidized in a mottled pattern; medium to coarse grained; rare weathered clasts at the base of the unit

Unit 3: Clay rich diamicton - similar colour to Unit 2; moderately indurated; blocky structure; Fe and Mn staining along fractures

Unit 2: Silty diamicton - Munsell 5Y5/3, olive; Rare clay rip-ups at base

Unit 1: Sand - Munsell 5Y 4/1 moist, dark grey; trough to planar to horizontally bedded, medium and coarse sand, generally fining up section; lower contact covered

THE PARRY BAY COMPOSITE SECTION
(48°22'25"N, 123°31'25"W)

Access: The Parry Bay section is accessed via the western-most Whitty's Lagoon Park entrance, approximately 15 kilometers southwest of Victoria. From Victoria take the #1 highway and turn right onto the Colwood exit (highway 14). Follow highway 14 until the Metchosin exit and turn left on Metchosin road. Follow Metchosin road for ~5 kilometers across the bridge at the Metchosin golf coarse, then take the next left . At the end of this road is the west entrance and parking lot of Whitty's Lagoon Regional Park. The Parry Bay section is a 10 to 15 minute walk southwest along the beach. The lowest diamicton is another 10 to 15 minute walk southwest along a boulder lag beach.

Composite Section: HB92-84, 112 and 117.
Unit Summaries: The Composite Parry Bay Section

Unit 1 (0 to 1.5 m): Massive, well indurated, sandy diamicton. This unit has a maximum thickness of 1.5 meters from the modern beach. It has a fresh, moist colour of 5Y 4/2 Olive Grey (Munsell, 1975) and is composed of approximately 25 per cent clasts and 75 per cent matrix. The matrix texture is approximately 2 per cent clay, 23 per cent silt and 75 per cent sand with small pebbles (sedograph results HB92 S53). The maximum long axis diameter of the clasts is 0.4 to 0.5 meters but average 0.02 to 0.03 meters; they are rounded to subrounded and well striated. The lithology of these clasts is dominated by mafic volcanics, plagioclase porphyry, siltstone and chert. A weak northwest to southeast trending fabric is apparent in this unit (averaging a 7° dip towards 297°) . The lower contact is covered by the modern beach.

Interpretation: The silty, indurated and massive nature of this unit combined with the many rounded to sub-rounded and striated clasts suggests a subglacial origin for this deposit. The lithology could easily find its source on Vancouver Island from the Metchosin volcanics, Catface intrusions and the Leech River Formation's cherts, argillites and volcanics (Muller, 1982) to the west and northwest of this section. The fabric also tend to imply a Vancouver Island provenance.

Unit 2 (~1m): Poorly bedded, well sorted clay and fine silt with rare pebbles. This unit tends to coarsen up section. The lower contact is sharp and unconformable.

Interpretation: The well sorted fines and rare pebbles in this unit suggest a subaqueous (either marine, lagoonal or lacustrine) depositional environment, however, the pebbles appear to represent either periods of higher flow regime or possibly glacial dropstones. Lack of detail prevents an accurate interpretation.

Unit 3 (15 to 33 m): Well sorted, finely laminated silt to fine sand, coarsening upward. Mostly 5Y 6/3 moist, pale olive (Munsell, 1975) with coarser units showing increased iron staining. Laminations range from 0.001 meters to 0.03 meters in thickness and are generally horizontal to sub-horizontal. Rare clay beds are present one of which is overlain by a thin, extensive lens of medium sand with granitic granules. The lower contact is covered and thickly vegetated in most places.

Interpretation: This unit lacks cross-bedding of any kind which suggests a low flow regime, depositional environment; possibly deltaic or antidunal. The coarsening nature suggests a distal to more proximal source or merely a prograding deltaic environment. The rare clay beds with overlying sand and granitic granules may be a result of lateral channel shifts across the deltaic front.

Unit 4 (12-25 m): Interbedded sand and gravel with undulating beds of fine sand up to 0.12 meters thick and containing 2 meter lenses of highly oxidized medium to coarse sand and gravel. There are an increasing number of planar cross-beds towards the top of this unit which have an apparent dip of 14° towards 236°. Bed load deformation structures (i.e. pillow and flame structures) and oxidization also increases towards the units top. The sand and gravel lenses are moderately sorted with coarse gravel concentrated at the centers. The clasts in the lenses range from 0.01 to 0.03 meters, are sub- to well rounded and are mainly composed of siltstones and weathered granitoids. The lower contact is gradual and undulating.

Interpretation: Unit 4 appears to be a continuation of unit 3, with an increasing flow regime and thus an increasing bed load. The undulating beds of fine sand may represent antidunal fluvial features, however, the flame and pillow structures suggest sudden deformation and dewatering of poorly consolidated sediments by sudden loading. Lenses of sand and gravel suggest that this sudden loading may be a result of greater bedloads brought on by shifting fluvial channels and a higher flow regimes. The increase in planar cross-bedded sand and gravel up section also suggests a probable prograding deltaic environment.

Unit 5 (~13 m): An organic rich, discontinuous sandy silt approximately 30 meters wide with organic rich interbeds. The organic rich beds are most prevalent at the base of unit 5 and are generally a very dark greyish brown (5Y 3/2 , Munsell 1975). Wood from within these beds is compressed and lacking bark (in most cases), other organic material tends to be broken and reworked. This wood has been dated at 39 860+/- 2800 years before present (AECV 1732 C). The sand and silt beds contain minor

Unit summaries continued...

concentrations of coarse sand and small pebbles. The bedding is generally sub-horizontal and apparently dips towards the northeast. The lower contact is definitely erosive as the entire unit cuts a 30 meter wide section, 13 meters deep into unit 4.

Interpretation: Eroded into the strongly oxidized, cross-bedded sand and gravel of unit 4 are the interbedded silts and broken detrital organic sediments of unit 5. Following a period of erosion, probably fluvial, deposition of fine sands, silts and organics occurred as a result of flood plain or overbank deposition. The conventional radiocarbon date from wood found at the base of this unit shows indicates deposition 39 860+/- 2800 years before present (AECV 1732 C), suggesting a relatively warm climate at this time. Decreasing organics up section show either an increase in sediment input over time, or a cooling climatic trend towards the onset of the Late Wisconsinan glaciation.

Unit 6 (0-10.3 m): A discontinuous unit of sandy, poorly bedded diamicton interbedded with sand, gravel and silt units. This sandy diamicton is composed of approximately 20 per cent clasts and 80 per cent matrix. The matrix is composed of 5 to 10 per cent fine sand, approximately 30 per cent medium sand and 65 per cent coarse sand. Of the clast lithologies 80 per cent are mafic volcanics with lessening concentrations of granite, diorite and sedimentary rocks. The maximum clast size is 0.70 meters however, the average clast is only 0.02 to 0.05 meters. The silt and sand units are horizontally to sub-horizontally bedded and most prevalent at the unit's base; the gravel beds are moderately to well sorted, horizontal to sub-horizontally bedded, sometimes lenticular, and generally coarsen up section to a cobble concentration where the clasts are rounded to subrounded and well imbricated towards 180°. This unit averages one to two meters thick over much of the area but reaches thickness' of 10.3 meters in places and pinches out completely in other areas. The lower contact is erosional.

Unit 6 - Interpretation: The horizontal to sub-horizontal silt and sand found near the base of this unit suggests marine or lacustrine deposition and the stratified sand and gravel shows a fluvial influence. The stratification and the sandy nature of this diamicton suggests it to be a sub-aerial debris flow or flow till. The lithologies are indicative of local sources to the north and northwest but appear influenced by material from the coast mountains and Georgia basin.

Unit 7 (0.5 to 5m): Interbedded fine silt, sand and diamicton averaging 0.90 meters thick with a 30 per cent clast content. The clasts have a maximum long axis diameter of 0.12 meters but average 0.01 to 0.02 meters; there are numerous striated clasts. The clast lithology is predominantly (~85 %) mafic volcanic followed by granitic, dioritic, quartzitic and sedimentary rocks. The matrix of the diamicton is approximately 5 to 10 per cent clay, 30 per cent silt, 50 per cent fine to medium sand and 5 to 10 per cent coarse sand to small pebbles/granules. The lower contact is gradual.

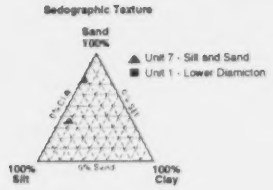
Interpretation: The interbedded silt, sand and diamicton with numerous striated clasts suggests an environment of deposition most closely associated with sub-aquatic till flows and interbedded glaciomarine or glaciolacustrine sediments. The lithology is indicative of local sources to the north and northwest with a coast mountain and Georgia basin influence. Fluvial deposits in this unit appear to flow towards 180°.

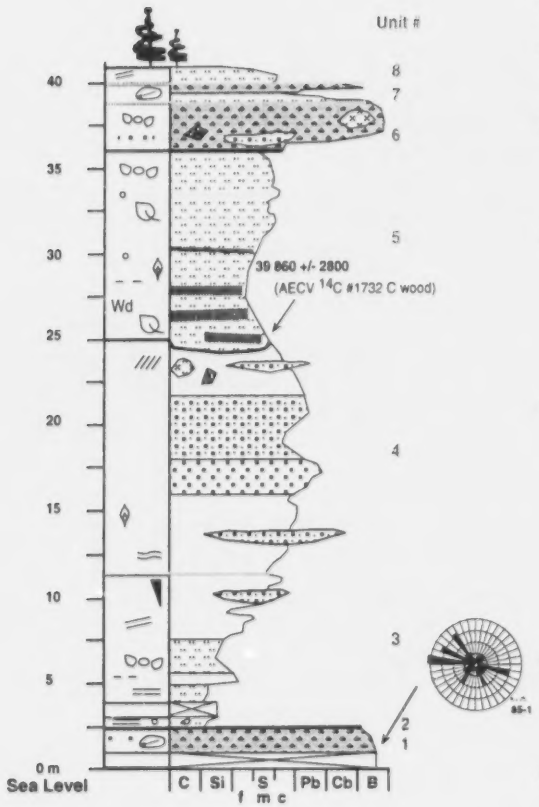
Unit 8 (1 to 5 m): Interbedded, pale brown, fine silts and sands (no Munsell colour was taken). Laminations range from 0.002 meters to 0.01 meters with rare clay rich laminations less than 0.002 meters thick. The lower contact is gradual. (See HB92 S64 for texture).

Interpretation: This unit appears to represent a depositional, lacustrine or marine basin.

COMPOSITE PARRY BAY SECTION

48°22'25"N 123°31'25"W





Unit 8 (1-5 m): ~2 m of interbedded pale silt and sand

Unit 7 (0.5-5 m): 0.9 m of interbedded silt sand and diamicton. Many striated clasts

Unit 6 (0-10.3 m): A discontinuous sandy diamicton interbedded with silt and sand beds and rare gravel lenses

Unit 5 (~13 m): Organic rich, interbedded fine sand and silt and distrubed organics and silts

Unit 4 (~25 m): Generally coarsening upward to coarse sand and gravel; rare disintigrating granit clasts at the top of the unit. Highly oxidized in coarse grained bed. Note the upper 15 meters is undulating and contains highly oxidized sand and gravel lenses. The planar cross-bedded sand has an apparent dip of ~16° towards 345°

Unit 3 (~10 m): Finely laminated, well sorted, sand and silt with rare clay beds, one of which is overlain by an extensive lense of sand and granitic granules

Unit 2 (~1 m): Interbedded, fine silt and clay with rare pebbles

Unit 1 (0-1.5 m): Massive, well indurated, sandy diamicton with mostly local lithology; fabric dips roughly north-west

THE TRIO GRAVEL PIT SECTION
(48°31'55"N, 123°22'50"W)

Access: This section is accessed via Cordova Bay Road.

Geomorphology: The Trio gravel pit exposes the eastern edge of the third of the five northwest trending drumlins that make up the Saanich Peninsula and Gulf Islands.

Section HB92-79
Unit Summaries: The Trio Gravel Pit Section

Unit 1 (0-5.5 m): Coarse sand and gravel, interbedded and well to moderately well sorted, colour when moist - dark grey brown (Munsell 2.5Y 4/2); bedding, planar to trough cross-bedded; sand dips up to 27° towards the south and southwest (240°-170°); sand well channeled as planoconcave trough cross-bedding is apparent and gravel is concentrated in the troughs (fig. 41). The gravel is less steeply dipping and more openwork than the sand which is approximately 70% matrix supported; openwork gravel beds are often manganese stained and, at the base of the section can even be found covered with clay-skins; the gravel beds are sometimes found to cut erosively into sand beds. Clasts are generally rounded to well rounded but rare angular clasts can be found; clasts average in size between 1 and 2 cm (a-axis diameter) a maximum clast size is approximately 30 cm. (Samples: Shells in lower 1 meter of unit HB92-S38; charcoal in lower 1 meter of unit HB92-S39; bone in lower 1 meter of unit HB92-S40; good piece of wood found in lower 2 meters of this section HB92-S41). The lower contact is covered but this unit is thought to go quite deep according to the gravel pit manager.

Interpretation: This unit appears to represent a longitudinal bar or flood plain deposit . The bones, shells and wood suggest this was a near-shore marine environment.

Unit 2 (9-10 m): Deformed to planar cross-bedded sand with rare pebbles (1-1.5 cm a-axis diameter average) throughout (photo R5-15); the deformed beds near the base of this unit show some flame and compression structures; the compression structures are compressed towards 096°; the planar cross-bedded sands dip quite steeply [~10°] towards 096°; massive sand is located at the easterly end of the dipping sands and horizontally bedded laminated medium and fine sand is on top of the massive sand. The top 2-3 meters of this unit is a coarsening upward sequence of trough cross-bedded sand and gravel similar to unit 1 coarsening to horizontal to sub-horizontal interbedded gravel and sand. The lower contact with unit one abrupt and horizontal and the unit generally coarsens upward. Medium to well sorted sand, first horizontally bedded, then gently trough cross-bedded to sub-planar cross-bedded, dipping southward towards 170° and finally almost horizontal at the top of the unit. The beds average 1-1.5 cm thick and coarsening upwards).

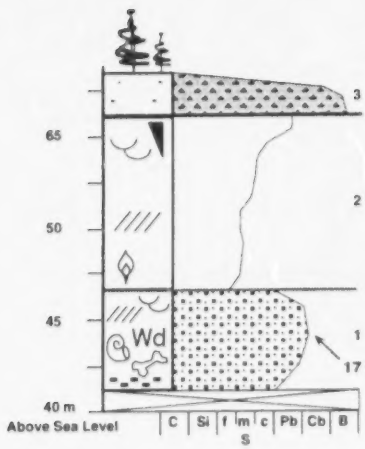
Interpretation: The base of this unit appears to represent a debris flow of sandy material which has settled and dewatered lower sediments. The planar cross-bedded sand may represent a low flow regime linguoid or transverse bar environment or a near shore deltaic deposit which are overlain by trough cross-bedded minor channel deposits.

Unit 3 (0-3 m): Diamicton, massive, very sandy; light orange brown (no Munsell). [Difficult to reach]. This unit is matrix supported; matrix 80%, clasts 20%; matrix is medium to coarse sand; clasts maximum a-axis size 20-30 cm, average size 10-15 cm and sub-rounded. The lower contact is erosional and irregular.

Interpretation: This unit appears to represent a sub-aerial debris flow deposit which has incorporated much of the lower gravel.

THE TRIO GRAVEL PIT SECTION

48°31'55"N 123°22'50"W



Unit 3 (0-3 m) : Diamicton; massive and very sandy; light orange brown and only moderately consolidated at best

Unit 2 (9-10 m) : Sand; deformed to planar cross-bedded with rare pebbles throughout; the deformed beds (i.e. compressed or flame structured) are at the base of this unit; the cross-bedding dips ~10° towards 096°

Unit 1 (0-5.5 m) : Sand and gravel; interbedded and moderately well sorted; planar cross-bedded sand dips 27° towards 170° to 240°; the gravel beds are commonly openwork and clasts in these beds are usually manganese stained or clay coated; rare bone, wood and shells are present at the bottom meter of this unit.

APPENDIX B: Lithology

Lithologic Breakdown by Provenance:

In choosing the rock types or suites that best characterized the various tills a connected line histogram of all the till lithologies was used to identify trends between the tills. The mafic, felsic and sedimentary rock suites most common to the various source areas were separated and plotted on a ternary diagram (fig. 9) to identify clustering. The most dominant rock types were then separated from each sample, i.e. siltstone, diorite, basalt and granitoids (granite and granodiorite), and plotted on a connected line histogram to narrowed down three lithologies which best differentiated the diamictons (dioritic, granitoid and basaltic lithologies). Data from these three lithologies was then plotted on a ternary diagram (fig. 17). Both methods proved useful at differentiated the diamictons, however, the ternary diagram of dioritic, granitoid and basaltic lithologies proved best at differentiating surface and lower diamictons visually and separated mafic Vancouver Island diamictons from the more felsic diamictons on the coast.

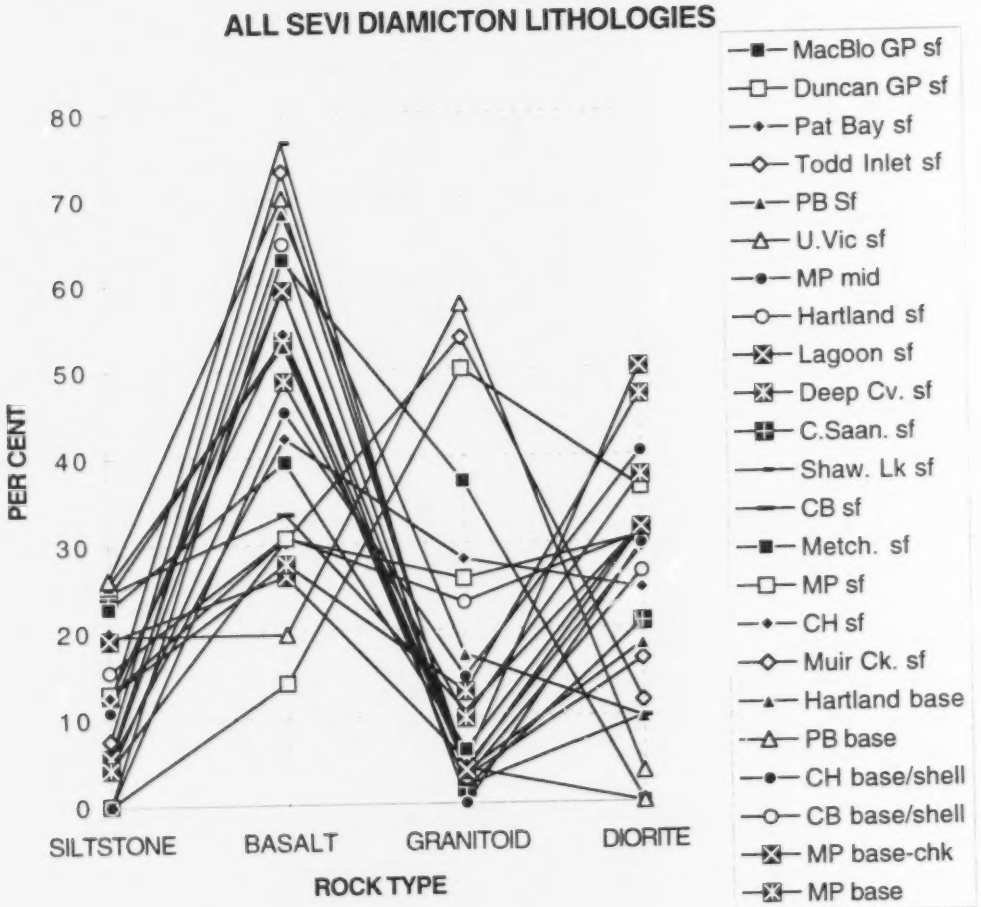
Rather than statistically correlate 23 diamicton lithology samples , each containing approximately 17 lithologies, ternary diagrams comparing known bedrock sources were used to visually separate diamictons on SEVI. One ternary diagram was created by grouping known Coast mountain, Georgia Depression and Vancouver Island lithologies based on the bedrock geology of each area to determine if, as a group, they would differentiate the tills. Two other ternary diagrams were created using the dominant bedrock types of each area. One ternary used sedimentary, granitoid and basaltic lithologies, while the other compared dioritic, granitoid and basaltic lithologic components aimed at identifying Vancouver Island versus Coast mountain provenance.

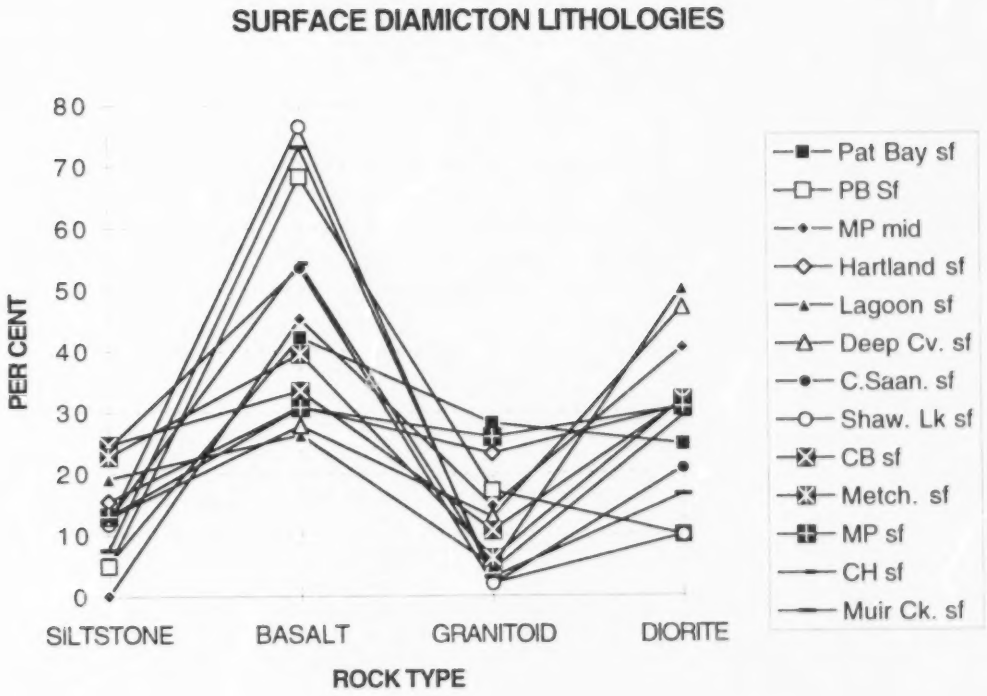
SITE #	UNIT #		AUGITE PORPHYRY
HB92-41	4	HB92-41/4 - MB CHEMAINUS GP. Only	0
HB92-50	2	HB92-50/2 - DUNCAN GP Only connvoluted	11
HB92-59	1	HB92-59/1 - SW PAT BAY-Only Diamict	0
HB92-62	2	HB92-62/2 - TODD INLET Only Diamict	0
HB92-85	5	HB92-85/5 - PARRY BAY Upper Diamicton	0
HB93-121	1	HB92-121/1 - MUIR PT. Lowest Diamicton	0
HB92-57	1	HB92-57/1 - MUIR PT Middle w tensn cks	3
HB92-107	1	HB92-107/1 - U. VICTORIA only Diamicton	0
HB92-63	1	HB92-63/1 - HARTLAND RD.CV Lower D	0
HB92-63	3	HB92-63/3 - HARTLAND RD.CV Upper D	0
HB92-64	1	HB92-64/1 - LAGOON RD. Only Diamicton	2
HB92-69	2	HB92-69/2 - DEEP COVE GP Only Diamicton	0
HB92-70	4	HB92-70/4 - CENTRAL SAAN GP. Only D	0
HB92-76	1	HB92-76/1 - SHAWNIGAN LK. Only Diamict	4
HB92-78	5	HB92-78/5 - CORDOVA BAY Upper Diamicton	6
HB92-85	1	HB92-85/1 - PARRY BAY Lower Diamicton	0
HB92-104	1	HB92-104/1 - METCHOSIN GP. Only Diamict	0
HB93-121	7	HB92-121/7 - MUIR PT. UPPER DIAMICTON	0
HB93-122	7	HB92-122/7 - COWICHAN HD. UPPER DIAM.	0
HB92-56	2	HB92-56/2 - MUIR CK. Only Diamicton	4
HB95-114	3	HB95-114 - Cowichan Head lower D Unit 3	0
HB95-78/1	1	HB95-78/1 - Cordova Bay Lower D. Unit 1	0
HB95-121/1B	1	HB95-121/1B - Muir Point Lowest Check	0

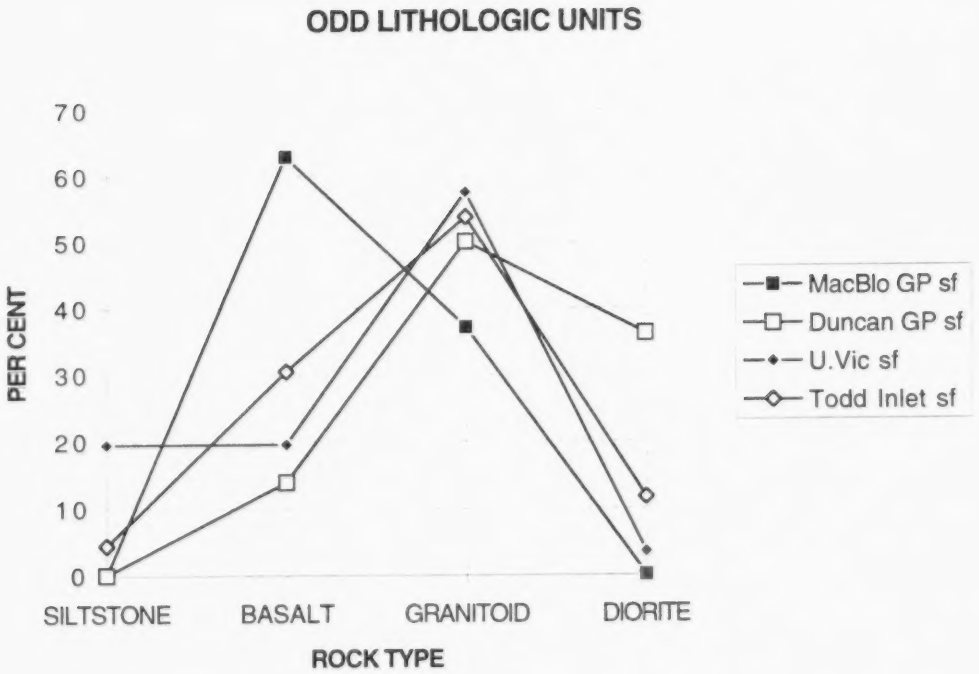
SITE #	BASALT	BIOTITE SHIST	GNEISS	CHLORITIC INTRUSIVE	GREEN VOLCANIC
HB92-41	39	0	5	0	15
HB92-50	5	0	0	0	24
HB92-59	24	0	0	0	16
HB92-62	21	0	0	0	16
HB92-85	28	0	0	0	23
HB93-121	35	0	0	0	21
HB92-57	28	0	0	9	4
HB92-107	17	0	3	0	3
HB92-63	29	8	0	4	21
HB92-63	8	10	0	4	22
HB92-64	11	0	0	0	21
HB92-69	13	0	0	0	13
HB92-70	31	0	2	0	14
HB92-76	39	0	1	0	19
HB92-78	19	0	0	0	13
HB92-85	35	0	0	4	20
HB92-104	26	0	6	0	2
HB93-121	19	0	3	0	4
HB93-122	26	0	2	0	16
HB92-56	49	0	0	0	0
HB95-114	22	0	0	0	0
HB95-78/1	44	0	0	1	0
HB95-121/1B	32	0	8	1	9

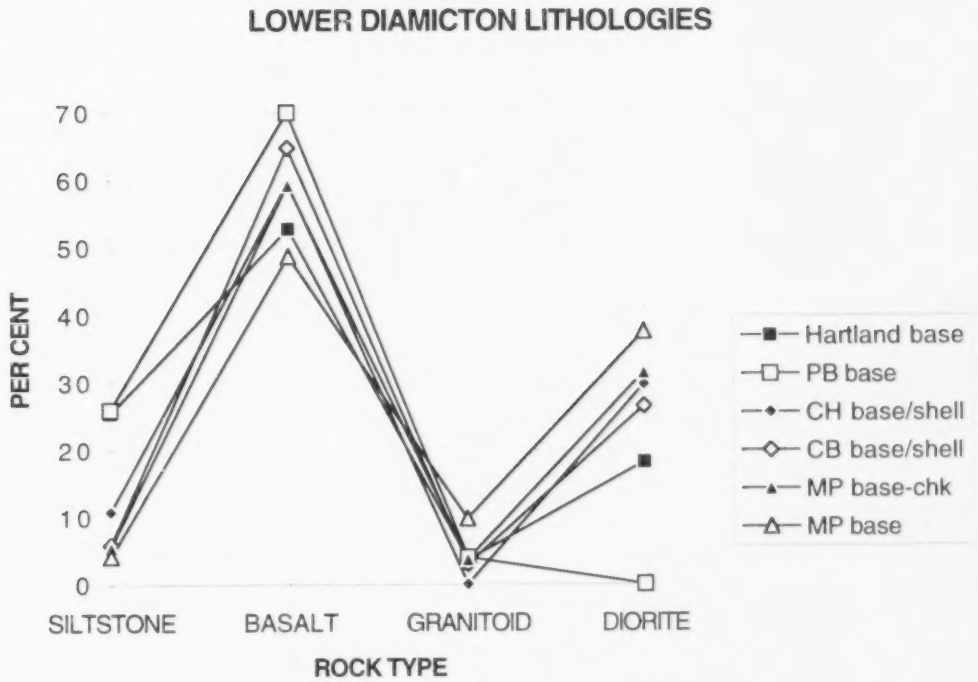
SITE #	MAFIC	DIORITE	CHERT	GRANITOID	K-FELDSPAR	PLAG. PORPHYRY
HB92-41	59	0	0	23	0	0
HB92-50	40	13	11	18	0	2
HB92-59	40	14	0	16	0	23
HB92-62	37	8	0	37	0	5
HB92-85	51	4	0	7	0	32
HB93-121	56	27	0	7	0	1.5
HB92-57	44	25	3	9	0	9
HB92-107	23	3	3	50	0	3
HB92-63	62	10	0	2	2	8
HB92-63	44	8	0	6	0	22
HB92-64	34	21	0	2	0	26
HB92-69	26	22	0	6	0	22
HB92-70	47	12	1	1	1	15
HB92-76	63	5	5	1	1	7
HB92-78	38	18	0	6	2	13
HB92-85	59	0	2	2	0	20
HB92-104	34	21	2	4	0	19
HB93-121	26	19	1	16	0	5
HB93-122	44	14	4	2	0	12
HB92-56	53	11	0	2	0	9
HB95-114	0	11	0	0	0	0
HB95-78/1	0	18	0	2	0	1
HB95-121/1B	22	17	2	2	0	3

SITE #	QUARTZITE	SANDSTONE	SILTSTONE	CONGLOMERATE	SEDIMENTARY	Misc
HB92-41	10	0	0	8	8	0
HB92-50	8	0	0	8	19	0
HB92-59	2	0	3	2	5	0
HB92-62	5	3	3	0	6	2
HB92-85	4	0	2	0	2	0
HB93-121	4	0	3	0	3	1.5
HB92-57	9	0	0	1	4	0
HB92-107	0	0	17	0	20	0
HB92-63	0	2	14	0	16	0
HB92-63	2	14	4	0	18	0
HB92-64	2	6	8	0	14	1
HB92-69	1	12	6	1	19	4
HB92-70	2	6	14	0	21	1
HB92-76	4	7	6	0	18	1
HB92-78	6	3	14	0	17	0
HB92-85	4	0	13	0	15	0
HB92-104	0	0	15	0	17	5
HB93-121	12	12	8	1	22	0
HB93-122	4	14	6	0	24	0
HB92-56	12	7	5	0	12	1
HB95-114	0	2	4	0	0	3
HB95-78/1	2	2	4	0	0	
HB95-121/1B	1	5	3	1	0	


ALL SEVI DIAMICTON LITHOLOGIES
PER CENT
80
70
60
50
40
30
20
10
0
SILTSTONE
BASALT
GRANITOID
DIORITE
ROCK TYPE
MacBlo GP sf
Duncan GP sf
Pat Bay sf
Todd Inlet sf
PB Sf
U.Vic sf
MP mid
Hartland sf
Lagoon sf
Deep Cv. sf
C.Saan. sf
Shaw. Lk sf
CB sf
Metch. sf
MP sf
CH sf
Muir Ck. sf
Hartland base
PB base
CH base/shell
CB base/shell
MP base-chk
MP base


SURFACE DIAMICTON LITHOLOGIES
80
70
60
50
40
30
20
10
0
PER CENT
SILTSTONE
BASALT
GRANITOID
DIORITE
ROCK TYPE
Pat Bay sf
PB Sf
MP mid
Hartland sf
Lagoon sf
Deep Cv. sf
C.Saan. sf
Shaw. Lk sf
CB sf
Metch. sf
MP sf
CH sf
Muir Ck. sf


ODD LITHOLOGIC UNITS
70
60
50
40
30
20
10
0
PER CENT
SILTSTONE
BASALT
GRANITOID
DIORITE
ROCK TYPE
MacBlo GP sf
Duncan GP sf
U.Vic sf
Todd Inlet sf


LOWER DIAMICTON LITHOLOGIES
70
60
50
40
30
20
10
0
PER CENT
SILTSTONE
BASALT
GRANITOID
DIORITE
ROCK TYPE
Hartland base
PB base
CH base/shell
CB base/shell
MP base-chk
MP base

APPENDICES C: Texture

SAMPLE #	Fines in Grams Total	PERCENT SAND Phi = -1 to 62.5	PERCENT SILT Phi = >62.5 to 9	PERCENT CLAY Phi = >9	SAND Phi = -1 to 62.5
HB92-S1	131.52	26.65	63.17	10.18	35.0494
HB92-S1 D	131.4193	28.28	67.20	4.52	37.1641
HB92-S2	141.10121	80.82	15.87	3.31	114.03861
HB92-S4	187.59089	86.59	11.25	2.16	162.43391
HB92-S5 U1	233.84212	74.92	23.72	1.35	175.20084
HB92-S5 U1 D	233.90424	75.25	23.42	1.33	176.0084
HB92-S6 U2	184.3004	67.13	31.22	1.65	123.7124
HB92-S7 U3	198.58259	75.28	24.17	0.56	149.48574
HB92-S8 U1	160.14109	65.53	28.56	5.91	104.93605
HB92-S9 U2	124.83338	51.06	36.30	12.64	63.73506
HB92-S10 U1	113.12962	56.46	30.64	12.90	63.86753
HB92-S10 U1 D	113.07981	56.44	30.44	13.13	63.81772
HB92-S11 U2	191.7684	76.12	21.30	2.57	145.982
HB92-S12 U1	163.08228	50.12	39.75	10.13	81.73808
HB92-S14	232.93417	74.35	23.66	1.98	173.1919
HB92-S15	158.46	73.25	23.37	3.38	116.07508
HB92-S15 Dup	158.64152	72.91	23.77	3.32	115.66666
HB92-S16	206.8321	70.01	28.68	1.30	144.81234
HB92-S16 U2	195.36	70.04	28.27	1.69	136.83921
HB92-S18 U1	235.02465	75.51	22.78	1.70	177.4754
HB92-S18 U1 D	234.90155	76.02	22.25	1.73	178.5833
HB92-S21 U1	114.27264	71.40	21.53	7.07	81.58992
HB92-S22 U1	166.72972	69.10	27.05	3.85	115.21618
HB92-S23 U3	207.63	56.90	40.58	2.52	118.15031
HB92-S25	178.07458	81.15	13.87	4.97	144.51588
HB92-S26	155.42	43.07	43.60	13.32	66.94535
HB92-S26 D	156.1596	41.33	45.11	13.56	64.54165
HB92-S27	127.62	77.50	20.57	1.93	98.91
HB92-S28 U2	151.35	78.41	17.26	4.33	118.67408
HB92-S29 U3	113.34348	61.07	23.39	15.54	69.21654
HB92-S31 U1	111.07	61.46	19.35	19.19	68.266
HB92-S31 U1 D	111.2005	61.31	19.64	19.05	68.179
HB92-S33	146.45376	77.57	12.66	9.77	113.60528
HB92-S35 U4	161.44422	80.77	15.42	3.81	130.39606
HB92-S44 U1	199.17276	68.01	27.80	4.20	135.44796
HB92-S51	187.73628	83.14	13.82	3.04	156.08758
HB92-S52	144.30197	78.58	18.12	3.30	113.38698
HB92-S53	130.52079	76.64	21.71	1.65	100.03025
HB92-S55	165.82441	73.86	15.21	10.93	122.48025
HB92-S55 D	165.78	73.72	14.44	11.84	122.21379
HB92-S56	127.61968	70.58	18.02	11.40	90.07098
HB92-S57	174.96914	73.09	22.80	4.10	127.89302
HB92-S59	191.68919	84.51	10.74	4.76	161.98835
HB92-S60	238.09096	91.88	7.61	0.51	218.75784
HB92-S61	65.64	57.83	35.66	6.51	37.9626
HB92-S61 D	65.6966	57.70	29.94	12.36	37.906
HB92-S64	153.16	36.25	54.50	9.25	55.52083
HB92-S65	283.76869	82.36	15.29	2.35	233.70882
HB92-S67	113.24854	46.65	36.31	17.04	52.83336
HB93-S1	207.48133	77.95	19.80	2.25	161.73153

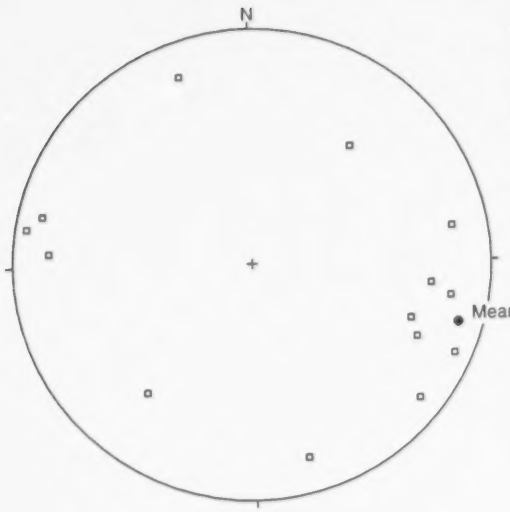
SAMPLE #	SILT Phi = >62.5 to 9	CLAY Phi = >9	#40<=#10 (CS/vCS) Phi = -1 to 1.25 ~V.COARSE-COARSE SAND	#230 <=#40 (vFS/MS) Phi = 1.25 to 4.0 MED-V.FINE SAND
HB92-S1	83.0775	13.3931	5.62	25.2
HB92-S1 D	88.3139	5.9413	5.62	25.2
HB92-S2	22.39862	4.66398	42.59	69.75
HB92-S4	21.096	4.06098	86.65	74.65
HB92-S5 U1	55.47316	3.16812	62.7	108.96
HB92-S5 U1 D	54.78984	3.106	62.7	108.96
HB92-S6 U2	57.5424	3.0456	32.95	86.68
HB92-S7 U3	47.99414	1.10271	54.48	91.12
HB92-S8 U1	45.73806	9.46698	33.45	69.49
HB92-S9 U2	45.3167	15.78162	7.16	54.23
HB92-S10 U1	34.66776	14.59433	16.11	47.11
HB92-S10 U1 D	34.41871	14.84338	16.11	47.11
HB92-S11 U2	40.8496	4.9368	54.4	88.92
HB92-S12 U1	64.82378	16.52042	14.58	64.81
HB92-S14	55.12203	4.62024	48.12	120.58
HB92-S15	37.03008	5.35484	34.34	78.74
HB92-S15 Dup	37.71078	5.26408	34.34	78.74
HB92-S16	59.32882	2.69094	38.24	102.6
HB92-S16 U2	55.22472	3.29607	36.33	96.84
HB92-S18 U1	53.5485	4.00075	52.32	120.97
HB92-S18 U1 D	52.25595	4.0623	52.32	120.97
HB92-S21 U1	24.60576	8.07696	32.54	47.38
HB92-S22 U1	45.09492	6.41862	41.9	69.86
HB92-S23 U3	84.24974	5.22995	36.16	76.38
HB92-S25	24.70342	8.85528	55.46	87.58
HB92-S26	67.76585	20.7088	9.31	53.66
HB92-S26 D	70.4469	21.17105	9.31	53.66
HB92-S27	26.25	2.46	25.05	72.45
HB92-S28 U2	26.1197	6.55622	42.19	74.1
HB92-S29 U3	26.51286	17.61408	10.96	56.33
HB92-S31 U1	21.489	21.315	11.67	55.9
HB92-S31 U1 D	21.837	21.1845	11.67	55.9
HB92-S33	18.53424	14.31424	45.58	67.08
HB92-S35 U4	24.89773	6.15043	47.94	80.68
HB92-S44 U1	55.36092	8.36388	49.78	82.88
HB92-S51	25.94862	5.70008	77.32	77.21
HB92-S52	26.15146	4.76353	54.61	57.69
HB92-S53	28.34099	2.14955	31.43	66.12
HB92-S55	25.22488	18.11928	26.54	94.83
HB92-S55 D	23.93699	19.62922	26.54	94.83
HB92-S56	22.99374	14.55496	14.65	73.95
HB92-S57	39.90168	7.17444	40.79	84.99
HB92-S59	20.58108	9.11976	48.18	112.73
HB92-S60	18.1248	1.20832	49.24	168.33
HB92-S61	23.4041	4.2733	3.28	34.06
HB92-S61 D	19.6685	8.1221	3.28	34.06
HB92-S64	83.47071	14.16846	12.15	38.34
HB92-S65	43.39239	6.66748	35.45	194.71
HB92-S67	41.11674	19.29844	5.54	46.31
HB93-S1	41.07748	4.67232	68.46	90.4

SAMPLE #	Sedo Phi->2-3 -250-125 um FINE SAND	Sedo Phi>3-4 <125-62.5 VERY FINE SAND	SEDO Phi>4-5 <62.5-31 um COARSE SILT	Phi >5-6 <31-15.6 um MEDIUM SILT
HB92-S1	3.021	1.2084	11.6812	34.8422
HB92-S1 D	5.9413	0.4028	11.6812	36.0506
HB92-S2	1.20918	0.48943	3.77149	5.41252
HB92-S4	0.55377	0.58014	3.21714	4.61475
HB92-S5 U1	2.04996	1.49088	11.8028	16.71028
HB92-S5 U1 D	2.29844	2.04996	12.424	16.1512
HB92-S6 U2	2.0088	2.0736	13.0248	15.8112
HB92-S7 U3	1.78534	2.1004	11.97228	15.753
HB92-S8 U1	1.36872	0.62733	3.25071	10.72164
HB92-S9 U2	1.45774	0.88732	4.1197	9.88728
HB92-S10 U1	0.54791	0.09962	0.29886	2.29126
HB92-S10 U1 D	0.29886	0.29886	0.64753	1.59392
HB92-S11 U2	1.9844	0.6776	5.6144	11.132
HB92-S12 U1	1.6772	0.67088	1.42562	8.97302
HB92-S14	3.14433	1.34757	10.01052	15.46497
HB92-S15	2.63204	0.36304	5.12794	8.80372
HB92-S15 Dup	2.08748	0.49918	5.17332	9.076
HB92-S16	3.01129	0.96105	10.37934	15.50494
HB92-S16 U2	2.05227	1.61694	9.01755	13.55742
HB92-S18 U1	2.76975	1.41565	11.50985	15.20285
HB92-S18 U1 D	3.50835	1.78495	10.52505	14.772
HB92-S21 U1	1.49952	0.1704	2.35152	4.97568
HB92-S22 U1	2.4687	0.98748	7.79012	14.04416
HB92-S23 U3	4.08887	1.52144	15.30949	29.4779
HB92-S25	1.08934	0.38654	3.02204	4.98988
HB92-S26	2.86595	1.1094	7.0262	18.3051
HB92-S26 D	0.3698	1.20185	8.5054	18.02775
HB92-S27	0.69	0.72	5.82	7.89
HB92-S28 U2	1.71794	0.66614	3.47094	6.59128
HB92-S29 U3	1.92654	0	0.41283	4.86222
HB92-S31 U1	0.5655	0.1305	0.174	1.6965
HB92-S31 U1 D	0.522	0.087	0.609	1.6095
HB92-S33	0.6752	0.27008	1.99184	3.81488
HB92-S35 U4	1.57872	0.19734	3.42056	5.45974
HB92-S44 U1	1.9914	0.79656	8.82854	14.86912
HB92-S51	1.39188	0.1657	3.04888	7.32394
HB92-S52	0.60743	0.47955	4.12413	6.52188
HB92-S53	1.62043	0.85982	5.39041	7.2754
HB92-S55	0.66615	0.4441	1.99845	3.9969
HB92-S55 D	0.31087	0.53292	2.30932	3.50839
HB92-S56	1.47098	0	1.23872	2.86454
HB92-S57	0.9828	1.13022	6.97788	9.53316
HB92-S59	0.40053	0.67782	2.43399	3.60477
HB92-S60	0.47104	0.7168	4.54656	6.20544
HB92-S61	0.4811	0.1415	0.5377	3.4526
HB92-S61 D	0.4811	0.0849	0.849	3.2545
HB92-S64	3.18277	1.84806	20.32866	28.64493
HB92-S65	1.66687	1.88195	12.20579	12.52841
HB92-S67	0.55314	0.43022	3.74906	8.97316
HB93-S1	2.28749	0.58404	4.81833	7.93321

SAMPLE #	Phi >6-9 <15.6-2 um FINE-V.FINE SILT	Phi >9 <2 um CLAY
HB92-S1	36.5541	13.3931
HB92-S1 D	40.5821	5.9413
HB92-S2	13.21461	4.66398
HB92-S4	13.26411	4.06098
HB92-S5 U1	26.96008	3.16812
HB92-S5 U1 D	26.21464	3.106
HB92-S6 U2	28.7064	3.0456
HB92-S7 U3	20.26886	1.10271
HB92-S8 U1	31.76571	9.46698
HB92-S9 U2	31.30972	15.78162
HB92-S10 U1	32.07764	14.59433
HB92-S10 U1 D	32.17726	14.84338
HB92-S11 U2	24.1032	4.9368
HB92-S12 U1	54.42514	16.52042
HB92-S14	29.64654	4.62024
HB92-S15	23.09842	5.35484
HB92-S15 Dup	23.46146	5.26408
HB92-S16	33.44454	2.69094
HB92-S16 U2	32.64975	3.29607
HB92-S18 U1	26.8358	4.00075
HB92-S18 U1 D	26.9589	4.0623
HB92-S21 U1	17.27856	8.07696
HB92-S22 U1	23.26064	6.41862
HB92-S23 U3	39.46235	5.22995
HB92-S25	16.6915	8.85528
HB92-S26	42.43455	20.7088
HB92-S26 D	43.91375	21.17105
HB92-S27	12.54	2.46
HB92-S28 U2	16.05748	6.55622
HB92-S29 U3	21.23781	17.61408
HB92-S31 U1	19.6185	21.315
HB92-S31 U1 D	19.6185	21.1845
HB92-S33	12.72752	14.31424
HB92-S35 U4	16.01743	6.15043
HB92-S44 U1	31.66326	8.36388
HB92-S51	15.5758	5.70008
HB92-S52	15.50545	4.76353
HB92-S53	15.67518	2.14955
HB92-S55	19.22953	18.11928
HB92-S55 D	18.11928	19.62922
HB92-S56	18.89048	14.55496
HB92-S57	23.39064	7.17444
HB92-S59	14.54232	9.11976
HB92-S60	7.3728	1.20832
HB92-S61	19.4138	4.2733
HB92-S61 D	15.565	8.1221
HB92-S64	34.49712	14.16846
HB92-S65	18.65819	6.66748
HB92-S67	28.39452	19.29844
HB93-S1	28.32594	4.67232

APPENDICES D: Fabric

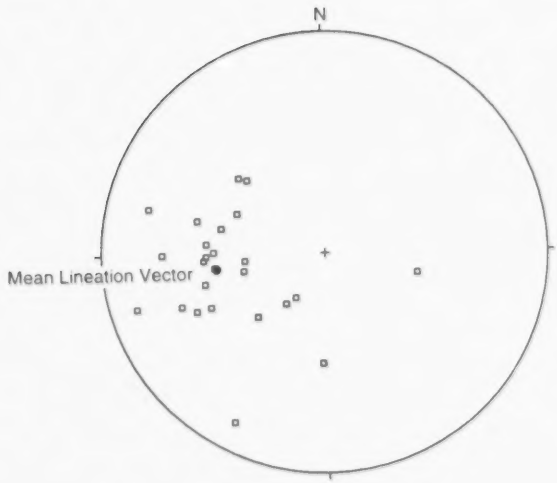
APPENDIX : Stereo Nets



Todd Inlet - Unit 2

Projection	Schmidt
Number of Sample Points	14
Mean Lineation Azimuth	106.9
Mean Lineation Plunge	10.2
1st Eigenvalue (E1)	0.693

▫ Trend and Plunge

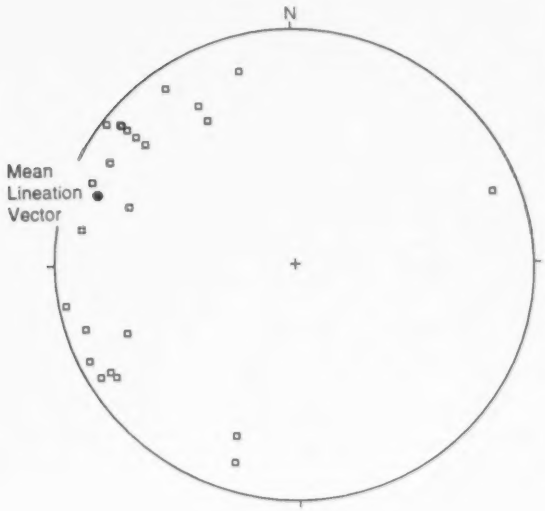


University of Victoria - Unit 1

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	262.2
Mean Lineation Plunge	48.7
1st Eigenvalue (E1)	0.800

▫ Trend and Plunge

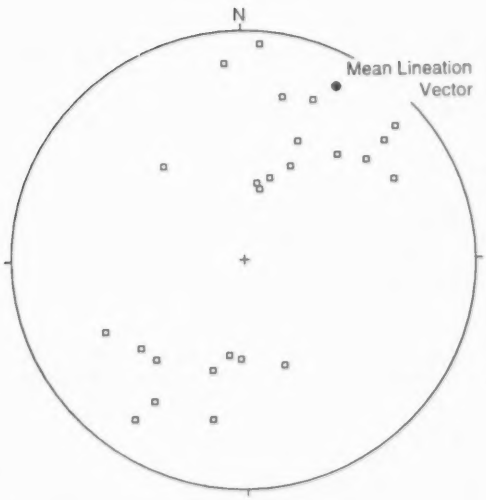
APPENDIX : Stereo Nets



Southern Pat Bay - Unit 1

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	290.2
Mean Lineation Plunge	13.1
1st Eigenvalue (E1)	0.659

▫ Trend and Plunge

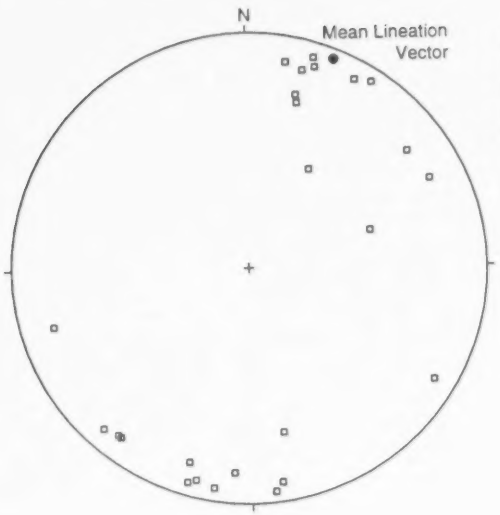


North Shawnigan Lake Road - Unit 1

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	28.6
Mean Lineation Plunge	14.2
1st Eigenvalue (E1)	0.539

▫ Trend and Plunge

APPENDIX : Stereo Nets

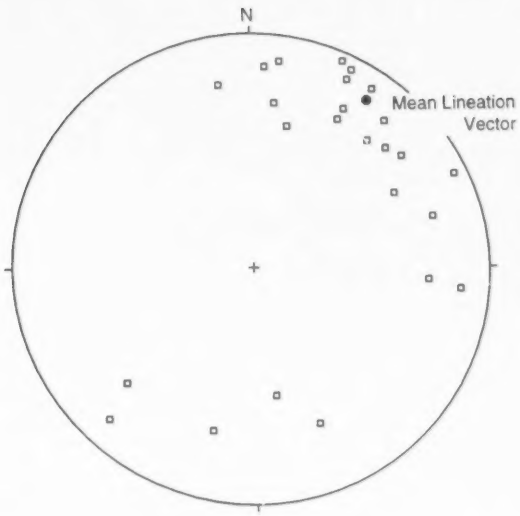


Muir Point - Unit 1

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	23.0
Mean Lineation Plunge	3.5
1st Eigenvalue (E1)	0.759

▫ Trend and Plunge

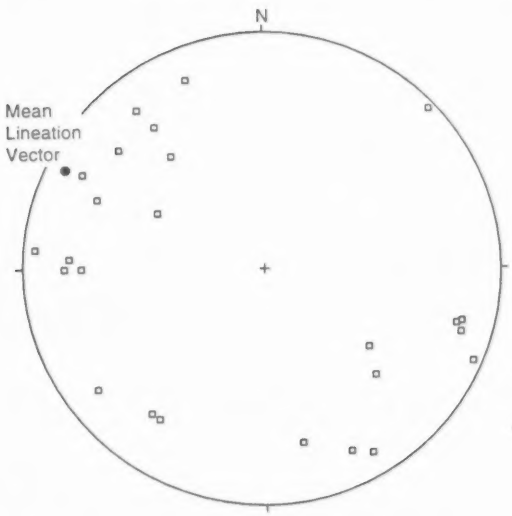
APPENDIX : Stereo Nets



Metchosin Gravel Pit - Unit 1

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	34.5
Mean Lineation Plunge	13.5
1st Eigenvalue (E1)	0.711

▫ Trend and Plunge

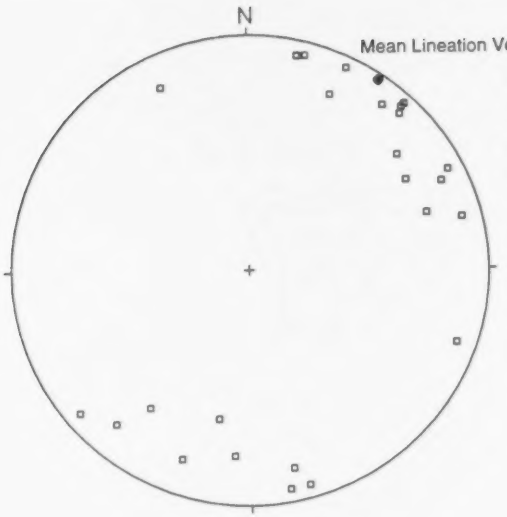


Parry Bay - Unit 1

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	297.2
Mean Lineation Plunge	7.3
1st Eigenvalue (E1)	0.618

▫ Trend and Plunge

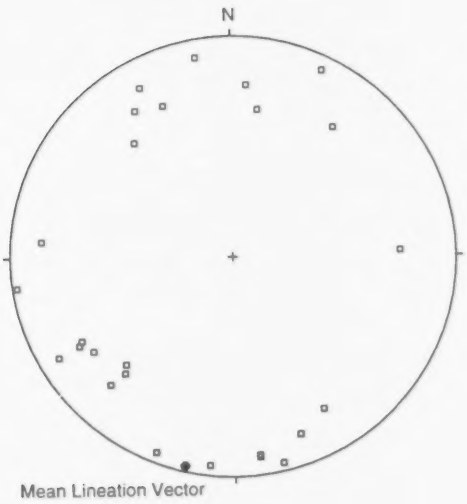
APPENDIX : Stereo Net



Lagoon Road - Unit 1

Projection ..... Schmidt
Number of Sample Points 26
Mean Lineation Azimuth 34.5
Mean Lineation Plunge 1.6
1st Eigenvalue (E1) 0.727

▫ Trend and Plunge

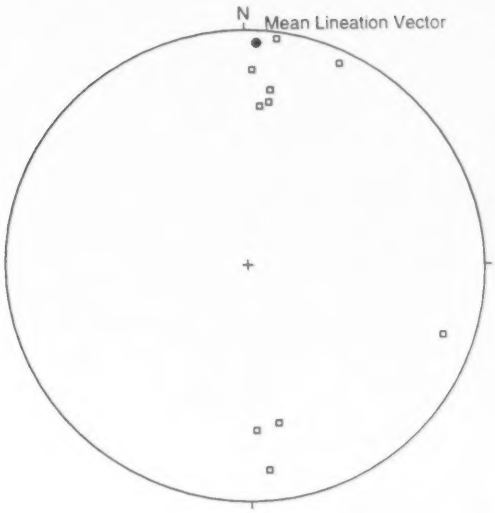


MacMillan Bloedel G.P. Chemainus - Unit 4

Projection ..... Schmidt
Number of Sample Points 26
Mean Lineation Azimuth 193.6
Mean Lineation Plunge 1.6
1st Eigenvalue (E1) 0.578

▫ Trend and Plunge

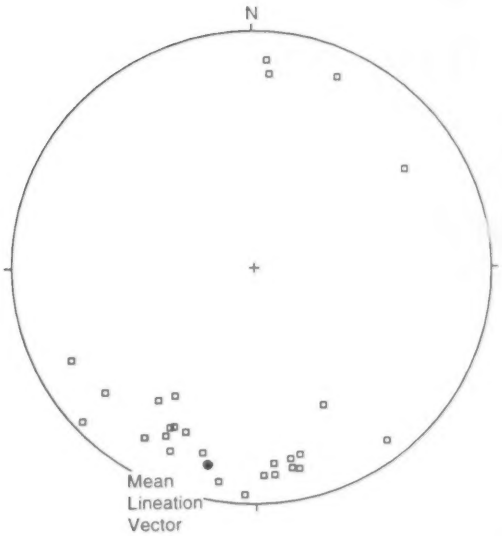
APPENDIX : Stereo Nets



Duncan Gravel Pit - Unit 2

Projection	Schmidt
Number of Sample Points	10
Mean Lineation Azimuth	3.0
Mean Lineation Plunge	4.7
1st Eigenvalue (E1)	0.752

o Trend and Plunge

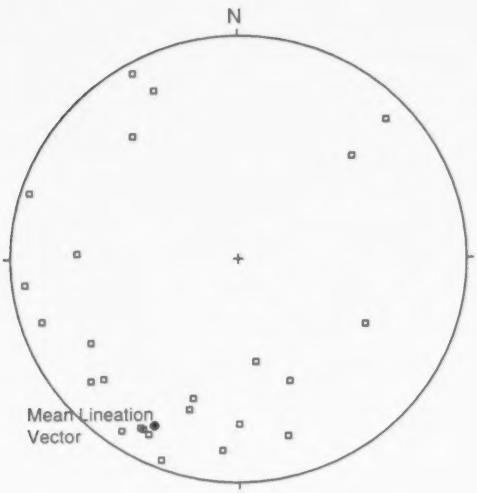


Hartland Road Curve - Unit 1

Projection	Schmidt
Number of Sample Points	27
Mean Lineation Azimuth	193.7
Mean Lineation Plunge	14.5
1st Eigenvalue (E1)	0.794

o Trend and Plunge

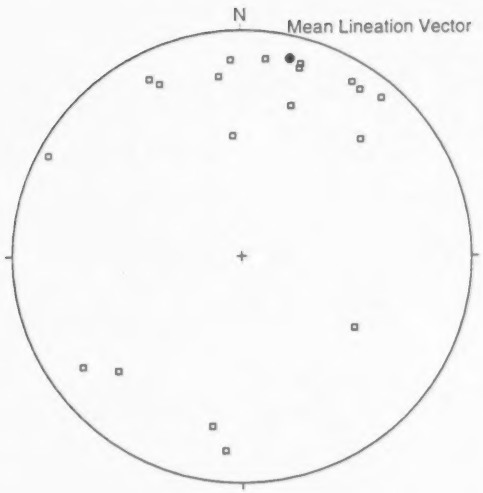
APPENDIX : Stereo Nets



Cowichan Head - Unit 6

Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	206.6
Mean Lineation Plunge	16.8
1st Eigenvalue (E1)	0.604

▫ Trend and Plunge

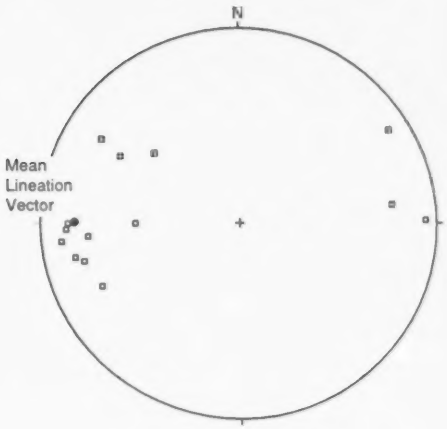


Central Saanich Gravel Pit - Unit 4

Projection	Schmidt
Number of Sample Points	19
Mean Lineation Azimuth	13.7
Mean Lineation Plunge	9.8
1st Eigenvalue (E1)	0.694

▫ Trend and Plunge

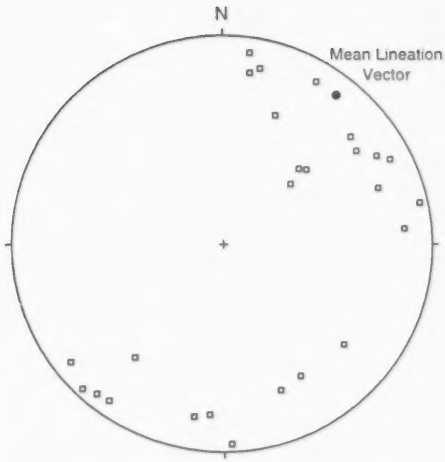
APPENDIX : Stereo Nets



Butler Brother's Gravel Pit - Unit 5

Projection ..... Schmidt
Number of Sample Points 15
Mean Lineation Azimuth 270.6
Mean Lineation Plunge 17.4
1st Eigenvalue (E1) 0.815

▫ Trend and Plunge



3km East of Chemainus Road Bridge - Unit 1

Projection ..... Schmidt
Number of Sample Points 26
Mean Lineation Azimuth 37.4
Mean Lineation Plunge 9.9
1st Eigenvalue (E1) 0.665

▫ Trend and Plunge

APPENDICES E: Field Records

	A	B	C	D	E	F	G	H	I	J
1	DONE	DATE	BY	MAP SHEET	NTS #	OPEN FILE	LOCATION	NOTES	SAMPLES	Sample Use
2		22-May	HB	VICTORIA	92 B/6	1993-23	BEACON HILL	HB92-1	NONE	
3		26-May	HB	SIDNEY	92 B/11	1993-24	ISLAND VIEW BEACH SEE COWICHAN HEAD	HB92-2	NONE	
4		6-Jul	HB	SHAWNIGAN LAKE	92 B/12	1993-26	MALAHAT CHALET, W SIDE OF ROAD	HB92-3	HB92-S3 (TILL)	
5		6-Jul	HB	SHAWNIGAN LAKE	92 B/12	1993-26	SOOKE LAKE, EAST SIDE	HB92-4a		
6		6-Jul	HB	SHAWNIGAN LAKE	92 B/12	1993-26	SOOKE LAKE, EAST SIDE	HB92-4b		
7		6-Jul	HB	SHAWNIGAN LAKE	92 B/12	1993-26	SOOKE LAKE, EAST SIDE	HB92-4c		
8		6-Jul	HB	SHAWNIGAN LAKE	92 B/12	1993-26	SOOKE LAKE, EAST SIDE	HB92-4&5	GET 2	
9	X	6-Jul	HB	VICTORIA	92 B/6	1993-23	RD CUT 300m W OF PAT B/McKENZIE INT	HB92-6		
10	X	7-Jul	HB	DUNCAN	92 B/13	1993-27	LADYSMITH AREA RIVER WEST BANK	HB92-7	HB92-S25	Texture
11	X	7-Jul	HB	DUNCAN	92 B/13	1993-27	LADYSMITH AREA RIVER EAST BANK	HB92-8	HB92-S26	Texture
12	X	7-Jul	HB	DUNCAN	92 B/13	1993-27	LADYSMITH FOUNDATION CUT	HB92-9	NONE	
13	X	7-Jul	HB	DUNCAN	92 B/13	1993-27	LADYSMITH IR GRAVEL PIT	HB92-10	GET UNITS 2&3	
14		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	SHAWNIGAN LAKE &W TOWARDS DRUMLIN	HB92-11	NONE	
15		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	S.L.&W/ GRAVEL PIT	HB92-12	GET DETAILS	
16		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	S.L. & W/ROAD	HB92-13	NONE	
17		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	S.L. & W/ROAD JUST PAST GAS STATION	HB92-14	SEE HB92-76	
18		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	S.L. & W/ON LOGGING ROAD	HB92-15	GET SAMPLE	
19		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	S.L. & W/ON LOGGING ROAD	HB92-16	NONE	
20		8-Jul	HB, NR	SHAWNIGAN LAKE	92 B/12	1993-26	S.L. & W/ON W SIDE OF LOGGING ROAD	HB92-17	HB92-S1 (SILT)	Texture
21		8-Jul	HB, NR	SIDNEY	92 B/11	1993-24	COWICHAN HEAD	HB92-18	GET NOTES&SAMPLES	
22	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MAPLE BAY	HB92-19	NONE	
23	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MAPLE BAY &W/N SIDE OF HERD ROAD	HB92-20	NONE	
24	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB&W/FARMER'S FIELD S OF HERD ROAD	HB92-21	GET CLAYS	
25	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB&W/ALONG HERD ROAD	HB92-22	NONE	
26	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB&W/ALONG HERD ROAD	HB92-23	NONE	
27	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB&W/HERD ROAD,N&S FACES W of bridge	HB92-24	GET DIAMICT&CLAY	
28	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB&W/800m S OF BRIDGE ON MAYS ROAD	HB92-25	NONE	
29	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB &W/HERD ROAD SMALL N SIDE EXPOSR	HB92-26	HB92-S2	Texture
30	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB &W/HERD ROAD TERRAIN	HB92-27	NONE	
31	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	MB &W/ HERD AT RAILROAD TRACKS	HB92-28	NONE	
32	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	DUNCAN ASPHALT &PAVING PIT	HB92-29	ASK NAT	
33	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	A PIT-1KM S OF DUNCAN A&P PIT	HB92-30	GET	
34	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	LOOKOUT ROAD MT. PREVOST	HB92-31	NONE	
35	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	CAIRN ROAD MT. PREVOST	HB92-32	NONE	
36	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	FROM CAIRN PNT MT PREVOST TO LOOKOUT	HB92-33	NONE	
37	X	9-Jul	HB	DUNCAN	92 B/13	1993-27	1/3 WAY DOWN MT PREVOST ROAD	HB92-34	GET SAMPLE OF Cb	
38		11-Jul	HB,JB	SIDNEY	92 B/11	1993-24	BRENTWOOD-GOLDSTREAM/GUN RANGE	HB92-35	NONE	
39		11-Jul	HB,JB	SIDNEY	92 B/11	1993-24	B-G/MT WORK	HB92-36	GET SAMPLE	
40		11-Jul	HB,JB	SOOKE	92 B/5	1993-25	B-G/MT WORK	HB92-37	NONE	
41		11-Jul	HB,JB	SOOKE	92 B/5	1993-25	B-G/MT WORK	HB92-38	NONE	
42		11-Jul	HB,JB	SOOKE	92 B/5	1993-25	1 km E OF GOLDSTREAM PK ON TERRACE	HB92-39	GET SILTS	
43		11-Jul	HB,JB	SOOKE	92 B/5	1993-25	GOLDSTREAM PARK	HB92-40	NONE	

	H	K	L	M	N	O	P	Q	R	S	T
1	NOTES	LAT. North	LONG. West	PHOTOS	AIRPHOTO #	BR-STRIAE	FABRIC	MUN	B.ROCK DIP	LITH	etc.
2	HB92-1	48° 24' 25" N	123° 21' 10" W		BC82012-196						
3	HB92-2	48° 33' 45" N	123° 22' 10" W		BC82012-163						
4	HB92-3	48° 32' 35" N	123° 33' 50" W		BC82012-165						
5	HB92-4a	48° 33' 45" N	123° 40' 40" W								
6	HB92-4b	48° 32' 55" N	123° 42' 00" W								
7	HB92-4c	48° 32' 25" N	123° 41' 50" W								
8	HB92-4&5	48° 27' 45" N	123° 44' 15" W	R1 7-11 CP	4/4-166 5/3-191						
9	HB92-6	48° 29' 55" N	123° 23' 15" W		BC82012-195						
10	HB92-7	48° 59' 55" N	123° 50' 10" W		BC82007-087						
11	HB92-8	48° 59' 55" N	123° 50' 10" W	R1 12 49th	BC82007-087						
12	HB92-9	48° 59' 45" N	123° 46' 50" W	R1 13 &14	BC82007-087						
13	HB92-10	48° 59' 40" N	123° 46' 20" W	R1 15-17	BC82007-087	138 DEGREES					
14	HB92-11	48° 39' 20" N	123° 40' 20" W		BC82007-195						
15	HB92-12	48° 39' 25" N	123° 40' 40" W		BC82007-195 5						
16	HB92-13	48° 39' 23" N	123° 41' 10" W		BC82007-195 5						
17	HB92-14	48° 39' 20" N	123° 37' 20" W		BC82007-197 5						
18	HB92-15	48° ' " N	123° ' " W	R1 19	BC82007-193 5						
19	HB92-16	48° 37' 55" N	123° 50' 00" W	R1 20	BC82007-193 5						
20	HB92-17	48° 37' 50" N	123° 51' 55" W	R1 21 of NAT	BC82007-193 5						
21	HB92-18	48° 33' 20" N	123° 21' 40" W	R1 22-24 NR							
22	HB92-19	48° 48' 50" N	123° 36' 30" W	R2 1 CP	BC82007-142,3						
23	HB92-20	48° 49' 25" N	123° 37' 50" W		BC82007-143 7						
24	HB92-21	48° 49' 15" N	123° 37' 55" W		BC82007-143 7						
25	HB92-22	48° 49' 20" N	123° 39' 50" W		BC82007-142 7						
26	HB92-23	48° 49' 20" N	123° 39' 58" W		BC82007-142 7						
27	HB92-24	48° 49' 22" N	123° 40' 05" W		BC82007-142 7						
28	HB92-25	48° 49' 10" N	123° 40' 50" W		BC82007-142 7						
29	HB92-26	48° 49' 25" N	123° 40' 50" W		BC82007-142 7		GET				
30	HB92-27	48° 49' 30" N	123° 41' 45" W		BC82007-142 7						
31	HB92-28	48° 48' 50" N	123° 43' 40" W	R2 2&3	BC82007-142 7						
32	HB92-29	48° 48' 00" N	123° 45' 20" W	R2 4-12	BC82007-142 7						
33	HB92-30	48° 47' 40" N	123° 44' 50" W		BC82007-142 7						
34	HB92-31	48° 50' 05" N	123° 45' 30" W	R2 13	BC82007-142 7		GET				
35	HB92-32	48° 50' 00" N	123° 45' 45" W		BC82007-142 7	152					
36	HB92-33	48° 49' 55" N	123° 45' 50" W	R2 15-21	BC82007-142 7	162.5 AVE			083/14 NW		
37	HB92-34	48° 50' 40" N	123° 45' 55" W		BC82007-142 7						
38	HB92-35	48° 32' 40" N	123° 26' 45" W		BC82012-164 4						
39	HB92-36	48° 31' 57" N	123° 29' 55" W		BC82012-164 4						
40	HB92-37	48° 29' 32" N	123° 31' 10" W		BC82012-164 4						
41	HB92-38	48° 29' 35" N	123° 32' 25" W		BC82012-164 4						
42	HB92-39	48° 29' 20" N	123° 32' 40" W		BC82012-164 4						
43	HB92-40	48° 29' 05" N	123° 32' 45" W		BC82012-						

	A	B	C	D	E	F	G	H	I	J
1	DONE	DATE	BY	MAP SHEET	NTS #	OPEN FILE	LOCATION	NOTES	SAMPLES	Sample Use
44		JUL12,28	HB	DUNCAN	92 B/13	1993-27	CHEMAINOUS &W/MAC BLO GRAVEL PIT	HB92-41	HB92-S4 DIAMICT	Texture
45		28-Jul	HB	DUNCAN	92 B/13	1993-27	COMPLETED HB92-41 FABRIC	HB92-41	HB92-S24	
46	X	12-Jul	HB	DUNCAN	92 B/13	1993-27	C&W/EASTERN PENNISULA:ROADS END	HB92-42	NONE	
47	X	12-Jul	HB	DUNCAN	92 B/13	1993-27	C&W/HILL 500m W OF GOLF C CORNER	HB92-43	GET FINE SANDS	
48	X	12-Jul	HB	DUNCAN	92 B/13	1993-27	C&W/GRAVEL PIT W OF GOLF C ON ROAD	HB92-44	NONE	
49	X	12-Jul	HB	DUNCAN	92 B/13	1993-27	C&W/ON LOGGING ROAD	HB92-45	GET DIAMICTON	
50	X	12-Jul	HB	DUNCAN	92 B/13	1993-27	C&W/ON CURVE OF LOGGING ROAD	HB92-46	HB92-S5,6,&7	Texture
51		12-Jul	HB	DUNCAN	92 B/13	1993-27	LADYSMITH LOGGING ROAD WEST ON 49th	HB92-47	GET SAMPLE	
52	X	12-Jul	HB	DUNCAN	92 B/13	1993-27	LADYSMITH LOGGING ROAD WEST ON 49th	HB92-48	HB92-S27	Texture
53	X	21-Jul	HB	SIDNEY	92 B/11	1993-24	PAT BAY RV PARK	HB92-49	HB92-S8,S9	Texture
54	X	21-Jul	HB	DUNCAN	92 B/13	1993-27	COWICHAN LAKE ROAD EAST	HB92-50	S10, S11	Texture
55	X	21-Jul	HB	DUNCAN	92 B/13	1993-27	COWICHAN LAKE RD GRAVEL PIT	HB92-51	NONE	
56	X	21-Jul	HB	DUNCAN	92 B/13	1993-27	SKUTZ FALLS ROAD	HB92-52	NONE	
57	X	21-Jul	HB	DUNCAN	92 B/13	1993-27	SKUTZ FALLS	HB92-52.5	NONE	
58	X	21-Jul	HB	DUNCAN	92 B/13	1993-27	SKUTZ FALLS ROAD	HB92-53	S12	Texture
59		22-Jul	HB	VICTORIA	92 B/6	1993-23	McKENZIE AND BURNSIDE	HB92-54	NONE	
60		22-Jul	HB	SOOKE	92 B/5	1993-25	MUIR CREEK W ALONG BEACH	HB92-55	S13 UNIT 7	
61		27-Jul	HB,NR	SOOKE	92 B/5	1993-25	MUIR CK & MUIR PT. ADDITIONAL NOTES	HB92-55-57	NONE	
62		22-Jul	HB	SOOKE	92 B/5	1993-25	MUIR CREEK W ALONG BEACH	HB92-56	S14-geo	Texture
63		23-Jul	HB	SOOKE	92 B/5	1993-25	MUIR POINT	HB92-57	S15-geo, S16 U-1&3	Texture
64		25-Jul	HB,KD...	SIDNEY	92 B/11	1993-24	BEACH FRONT NEAR PAT BAY	HB92-58	NONE	
65		25-Jul	HB,KD...	SIDNEY	92 B/11	1993-24	BEACH FRONT SW OF PAT BAY	HB92-59	S17, S18-geo	Texture
66		25-Jul	HB,KD...	SIDNEY	92 B/11	1993-24	COLES BAY 2-3m ABOVE AVE. HIGH TIDE	HB92-60	S19, S20 (C14)	
67		25-Jul	HB,KD...	SIDNEY	92 B/11	1993-24	JUST N OF BRENTWOOD BAY	HB92-61	NONE	
68		25-Jul	HB,KD...	SIDNEY	92 B/11	1993-24	TODD INLET	HB92-62	S21	Texture
69	X	26-Jul	HB	SIDNEY	92 B/11	1993-24	CURVE JUST E OF HARTLAND RD DUMP	HB92-63	S22-geo, S23-geo	Texture
70	X	28-Jul	HB,JPB	DUNCAN	92 B/13	1993-27	N. OF CHEMAINOUS (LAGOON ROAD)	HB92-64	GET	
71		15-Aug	HB	DUNCAN	92 B/13	1993-27	COMPLETION OF LAGOON RD SECTION	HB92-64	HB92-S51???????	Texture
72	X	28-Jul	HB,JPB	DUNCAN	92 B/13	1993-27	49th ROAD GOING WEST	HB92-65	NONE	
73	X	28-Jul	HB,JPB	DUNCAN	92 B/13	1993-27	49th ROAD GOING WEST	HB92-66	NONE	
74	X	28-Jul	HB,JPB	DUNCAN	92 B/13	1993-27	49th ROAD GOING WEST	HB92-67	NONE	
75		30-Jul	HB	SIDNEY	92 B/11	1993-24	DEEP COVE READINGS ROAD	HB92-68	NONE	
76		30-Jul	HB	SIDNEY	92 B/11	1993-24	SW SIDE OF N SAANICH GRAVEL PIT	HB92-69	HB92-S28-geo,S29	Texture
77	X	31-Jul	HB	SIDNEY	92 B/11	1993-24	W SIDE OF CENTRAL SAANICH GRAVEL PIT	HB92-70	HB92-S30 C14	
78		3-Aug	HB,LS	SIDNEY	92 B/11	1993-24	COMPLETION OF C SAANICH GRAVEL PIT	HB92-70	HB92-S34,S35-geo C14	Texture
79	X	31-Jul	HB	SIDNEY	92 B/11	1993-24	LOCKSIDE ELEMENTARY EXCAVATIONS	HB92-71	NONE	
80		31-Jul	HB	VICTORIA	92 B/6	1993-23	TOP OF MOUNT DOUGLAS	HB92-72	NONE	
81	X	1-Aug	HB	VICTORIA	92 B/6	1993-23	PAT BAY HWY; 1 KM W OF CHRISTMAS HIL	HB92-73	HB92-S31,S32	Texture
82		2-Aug	HB,LS	VICTORIA	92 B/6	1993-23	FINLAYSON POINT	HB92-74	NONE	
83		2-Aug	HB,LS	VICTORIA	92 B/6	1993-23	1km E OF FINLAYSON PT. IN BAY	HB92-75	NONE	
84		2-Aug	HB,LS	SHAWNIGAN LAKE	92 B/12	1993-26	RCMP SECTION N. SHAWNIGAN LK ROAD	HB92-76	HB92-S33-geo	Texture
85		AUG 4,5	HB,LS	SIDNEY	92 B/11	1993-24	SENANUS ISLAND OFF BRENTWOOD	HB92-77	NONE	

	H	K	L	M	N	O	P	Q	R	S	T
1	NOTES	LAT. North	LONG. West	PHOTOS	AIRPHOTO #	BR-STRIAE	FABRIC	MUN	B.ROCK DIP	LITH	etc.
44	HB92-41	48° 54' 40" N	123° 42' 20" W	R2 23	82007-99-101		X	X		DONE	
45	HB92-41	48° 54' 40" N	123° 42' 20" W		BC82007-099 8				FRST008/33E		
46	HB92-42	48° 55' 20" N	123° 42' 10" W		BC82007-099				GET FROM MP		
47	HB92-43	48° 54' 40" N	123° 42' 50" W		BC82007-099						
48	HB92-44	48° 54' 35" N	123° 43' 20" W		BC82007-099						
49	HB92-45	48° 54' 20" N	123° 45' 50" W		BC82007-101						
50	HB92-46	48° 53' 55" N	123° 46' 10" W	R2 24	BC82007-087 9		not			GET	
51	HB92-47	49° 00' 20" N	123° 50' 45" W		82007-087 9		not				
52	HB92-48	48° 59' 30" N	123° 51' 45" W		82007-087 9			"			
53	HB92-49	48° 35' 05" N	123° 24' 10" W	R3-5,6 CP				"			
54	HB92-50	48° 49' 32" N	124° 00' 55" W	R3-7	BC82007-138		UNIT 2	"		UNIT 2	
55	HB92-51	48° 48' 55" N	123° 58' 20" W	R3-8 TO 11	BC82007-138						
56	HB92-52	48° 48' 10" N	123° 57' 35" W		BC82007-138						
57	HB92-52.5	48° 47' 10" N	123° 57' 00" W		BC82007-138						
58	HB92-53	48° 48' 15" N	123° 57' 25" W		BC82007-138				GNEISS		
59	HB92-54	48° 28' 10" N	123° 24' 15" W						125/07 NE?		
60	HB92-55	48° 22' 55" N	123° 52' 50" W	R3-12 TO 16	BC82012-207 2						
61	HB92-55-57			R4-9-14	BC82012-207 2						
62	HB92-56	48° 22' 45" N	123° 52' 05" W	R3-17	BC82012-207 2		"	"		"	"
63	HB92-57	48° 21' 25" N	123° 45' 00" W	R3-19 TO 24	BC82012-207 2		"	"		"	"
64	HB92-58	48° 38' 35" N	123° 28' 00" W					"			
65	HB92-59	48° 38' 03" N	123° 28' 40" W	R4-2,3	BC82007-199 5		"	"		"	
66	HB92-60	48° 37' 45" N	123° 27' 55" W		BC82007-199 5			"			
67	HB92-61	48° 35' 25" N	123° 27' 55" W		BC82007-199 5			"			
68	HB92-62	48° 33' 35" N	123° 28' 25" W	R4-4	BC82007-199 5		not	"		"	
69	HB92-63	48° 31' 50" N	123° 27' 15" W	R4-7,8	BC82007-164		"	"		"	
70	HB92-64	48° 58' 15" N	123° 47' 25" W		BC82007-087 9		GET	"		UNIT 1	
71	HB92-64	48° 58' 15" N	123° 47' 20" W				"				
72	HB92-65	48° 59' 30" N	123° 53' 07" W		BC82007-085 9			"			
73	HB92-66	48° 59' 15" N	123° 55' 10" W		BC82007-085 9						
74	HB92-67	48° 58' 50" N	123° 56' 20" W		BC82007-085 9						
75	HB92-68	48° 41' 20" N	123° 26' 45" W		BC82007-158 6	1/144 2/108			085/50 N		
76	HB92-69	48° 39' 25" N	123° 26' 00" W	R4 15,16	BC82007-179 5			"	FRST150/12	X	
77	HB92-70	48° 33' 40" N	123° 25' 45" W	R4 17-25	BC82012-163 4			"			
78	HB92-70	48° 33' 40" N	123° 25' 45" W				"	"	110/43 NE	X	
79	HB92-71	48° 30' 05" N	123° 21' 40" W		BC82012-163 4	F175 S175					
80	HB92-72	48° 29' 30" N	123° 20' 40" W	R4 26-33	BC82012-163 4	1/180 F 177		"			2
81	HB92-73	48° 28' 20" N	123° 23' 00" W					"			
82	HB92-74	48° 24' 25" N	123° 21' 50" W	R4 34,36;R5-1		F020 - 18		"	X		
83	HB92-75	48° 24' 27" N	123° 21' 30" W	R5 2 CS				"			
84	HB92-76	48° 39' 30" N	123° 37' 25" W				"	"		X	
85	HB92-77	48° 35' 30" N	123° 29' 15" W	R5-3	BC82012-163 4						

	A	B	C	D	E	F	G	H	I	J
1	DONE	DATE	BY	MAP SHEET	NTS #	OPEN FILE	LOCATION	NOTES	SAMPLES	Sample Use
86		6-Aug	HB,LS	VICTORIA	92 B/6	1993-23	CORDOVA BAY CLIFFS	HB92-78	HB92-S36,S37	
87	X	7-Aug	HB,LS	SIDNEY	92 B/11	1993-24	TRIO GRAVEL PIT	HB92-79	S38-S42	
88	X	8-Aug	HB,LS	DUNCAN	92 B/13	1993-27	CHEMAINOUS LOGGING RD AND WEST	HB92-80	NONE	
89	X	8-Aug	HB,LS	DUNCAN	92 B/13	1993-27	CHEMAINOUS LOGGING RD, PIT	HB92-81	NONE	
90	X	8-Aug	HB,LS	DUNCAN	92 B/13	1993-27	C.L R JUST E OF CHEMAINOUS R. BRIDGE	HB92-82	HB92-S43	
91		16-Aug	HB	DUNCAN	92 B/13	1993-27	CHEMAINOUS R. BRIDGE	HB92-82	HB92 S52-geo	Texture
92		12-Aug	HB, RH	SIDNEY	92 B/11	1993-24	HEAL LAKE, DRAINED	HB92-83	HB92-S44-S46	Texture
93		12-Aug	HB, RH	SIDNEY	92 B/11	1993-24	HEAL LAKE, DRAINED	HB92-84	NONE	
94		18-Aug	HB	SOOKE	92 B/5	1993-25	WITTY' S LAGOON/PARRY BAY SECTION	HB92-84?,85	HB92 S53-geo, S54	Texture
95		12-Aug	HB, RH	SOOKE	92 B/5	1993-25	WITTY'S LAGOON/PARRY BAY	HB92-85		
96		13-Aug	HB	SOOKE	92 B/5	1993-25	WITTY'S LAGOON/PARRY BAY	HB92-86	HB92-S47-S51-geo	S50-14C Text
97		14-Aug	HB	VICTORIA	92 B/6	1993-23	W. SIDE OF METCHOSIN GRAVEL PIT	HB92-87		
98		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	COWICHAN BAY MUD FLATS	HB92-88		
99		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	COWICHAN BAY MUD FLATS & S	HB92-89		
100		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	COWICHAN BAY (TOWN)	HB92-90		
101		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	GRAVEL HILL SUPPLIES (PIT)	HB92-91		
102		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	GRAVEL HILL SUPPLIES (PIT)	HB92-92		
103		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	COWICHAN VALLEY FARMER'S FIELD	HB92-93		
104		15-Aug	HB	DUNCAN	92 B/13	1993-27	JUST PAST BUTLER'S PIT, COWICHAN	HB92-94		FIND IN NOTES
105		15-Aug	HB	SHAWNIGAN LAKE	92 B/12	1993-26	COWICHAN LOGGING DETOUR	HB92-95		
106		15-Aug	HB	DUNCAN	92 B/13	1993-27	SOMENOS LAKE LOWLANDS	HB92-96		
107	X	19-Aug	HB	VICTORIA	92 B/6	1993-23	E. SIDE OF CLOVER POINT	HB92-97		
108	X	19-Aug	HB	VICTORIA	92 B/6	1993-23	WEATHER STATION LOOKOUT GONZALLY'S	HB92-98		
109	X	19-Aug	HB	VICTORIA	92 B/6	1993-23	FOUL BAY RD HOUSE EXCAVATION	HB92-99	HB92 S55	Texture
110	X	20-Aug	HB	VICTORIA	92 B/6	1993-23	N. SIDE OF WILLOW'S BEACH	HB92-100	HB92 S56	Texture
111	X	20-Aug	HB	VICTORIA	92 B/6	1993-23	ARBUTUS ROAD	HB92-101		
112	X	20-Aug	HB	VICTORIA	92 B/6	1993-23	NEAR UVIC S ... HILL	HB92-102		
113	X	21-Aug	HB	VICTORIA	92 B/6	1993-23	METCHOSIN GRAVEL PIT	HB92-103		
114	X	21-Aug	HB	VICTORIA	92 B/6	1993-23	SW SIDE OF METCHOSIN GRAVEL PIT	HB92-104	HB92 S57-geo	Texture
115	X	21-Aug	HB	VICTORIA	92 B/6	1993-23	NE SIDE TOP OF METCHOSIN GRAVEL PIT	HB92-105		
116	X	21-Aug	HB	VICTORIA	92 B/6	1993-23	N SIDE TOP OF METCHOSIN GRAVEL PIT	HB92-106		
117	X	21-Aug	HB	VICTORIA	92 B/6	1993-23	FINNERTY RD EXCAVATION UVIC	HB92-107	HB92 S58Lith-geo, S59	Texture
118	X	22-Aug	HB	SIDNEY	92 B/11	1993-24	BUTLER BROS. GRAVEL PIT (KEATING RD)	HB92-108	HB92 S60-geo	Texture
119	X	22-Aug	HB	SIDNEY	92 B/11	1993-24	ISLAND VIEW BEACH RD LOWLANDS	HB92-109		
120	X	22-Aug	HB	SIDNEY	92 B/11	1993-24	I.V.B. RD IRRIGATION POND	HB92-110		
121	X	22-Aug	HB	SIDNEY	92 B/11	1993-24	W SIDE OF VICTORIA AIRPORT	HB92-111	HB92 S61-geo	Texture
122		25-Aug	HB	SOOKE	92 B/5	1993-25	PARRY BAY	HB92-112+84	HB92 S62, 63, &64	Texture
123		25-Aug	HB	SOOKE	92 B/5	1993-25	EAST WHITTY'S PATH	HB92-113	HB92 S65-geo, S66	Texture
124		26-Aug	HB	SIDNEY	92 B/11	1993-24	COWICHAN HEAD	HB92-114	HB92 67	Texture
125		27-Aug	HB	SOOKE	92 B/5	1993-25	GOLDSTREAM S&G PIT	HB92-115		
126		27-Aug	HB	SIDNEY	92 B/11	1993-24	DOMINION OBSERVATORY	HB92-116		
127		27-Dec	HB &TG	SOOKE	92 B/5	1993-25	PARRY BAY (TOP)	HB92-117		

	H	K	L	M	N	O	P	Q	R	S	T
1	NOTES	LAT. North	LONG. West	PHOTOS	AIRPHOTO #	BR-STRIAE	FABRIC	MUN	B.ROCK DIP	LITH	etc.
86	HB92-78	48° 29' 40" N	123° 19' 25" W	R5 4,7 LS 3,4	BC82012-163 4	176 POOR	GET	*	042/31 E	X	
87	HB92-79	48° 31' 50" N	123° 22' 50" W	R5 9-18	BC82012-163 4			*	APPARENT		
88	HB92-80	48° 53' 25" N	123° 46' 40" W	R5-19	BC82007-101 8	O 15/ Y 165					
89	HB92-81	48° 50' 40" N	123° 49' 50" W		BC82007-101 8			*			
90	HB92-82	48° 50' 30" N	123° 54' 30" W	R5 20-22	BC82007-101 8			*	110/10 S		
91	HB92-82	48° 50' 30" N	123° 54' 30" W	R6 4-8			*	*	AD 17->125	X	
92	HB92-83	48° 32' 25" N	123° 27' 50" W	R5 23-25		-023	NONE	*	194/14 W		
93	HB92-84	48° 32' 25" N	123° 27' 50" W	R5 26							
94	HB92-84?,85	48° 22' 20" N	123° 31' 30" W	R6 9,10			*	*		X	
95	HB92-85	48° 22' 20" N	123° 31' 30" W				*	*	X	X	
96	HB92-86	48° 22' 25" N	123° 31' 25" W	R5 27-38			*	*		X	C14 HB92 S50
97	HB92-87	48° 23' 50" N	123° 29' 35" W			-010					
98	HB92-88	48° 44' 40" N	123° 37' 50" W								
99	HB92-89	48° 44' 25" N	123° 37' 30" W								
100	HB92-90	48° 44' 20" N	123° 37' 00" W								
101	HB92-91	48° 43' 10" N	123° 36' 00" W	R6 1-3					22-->048		
102	HB92-92	48° 44' 45" N	123° 41' 45" W						11-->072		
103	HB92-93	48° 24' 25" N	123° 21' 50" W		BC82007-162 6						
104	HB92-94	48° ' " N	123° ' " W		BC82007-162 6						
105	HB92-95	48° 44' 10" N	123° 46' 10" W		BC82007-162 6						
106	HB92-96	48° 47' 25" N	123° 42' 30" W								
107	HB92-97	48° 24' 15" N	123° 20' 50" W	R6 11,12	BC82012-196 3	S 012/F 008					
108	HB92-98	48° 24' 40" N	123° 19' 20" W		BC82012-196 3	S 011					
109	HB92-99	48° 25' 40" N	123° 19' 20" W		BC82012-196 3			*			
110	HB92-100	48° 26' 20" N	123° 17' 50" W		BC82012-196 3	S 165		*		x	
111	HB92-101	48° 27' 35" N	123° 16' 30" W		BC82012-196 3	F 163/ S 155					
112	HB92-102	48° 27' 45" N	123° 18' 00" W		BC82012-196 3						
113	HB92-103	48° 24' 25" N	123° 29' 35" W	R6 13-22	BC82012-194 3			*	*		CORE DATA
114	HB92-104	48° 24' 15" N	123° 29' 45" W	R6 23-24	BC82012-194 3	S 022	*	*		*	CORE DATA
115	HB92-105	48° 24' 45" N	123° 29' 10" W	R6 25	BC82012-194 3			*			CORE DATA
116	HB92-106	48° 24' 40" N	123° 29' 25" W	R6 26-28	BC82012-194 3						CORE DATA
117	HB92-107	48° 28' 10" N	123° 18' 15" W	R6 29-31	BC82012-196 3		*	*		*	
118	HB92-108	48° 33' 45" N	123° 25' 15" W	R6 32-37 R7-4			*	*			
119	HB92-109	48° 34' 20" N	123° 22' 10" W								
120	HB92-110	48° 34' 10" N	123° 22' 40" W					*			
121	HB92-111	48° 38' 55" N	123° 26' 30" W					*			ROLLING TOPO
122	HB92-112+84	48° 22' 30" N	123° 31' 15" W	R7 5-11				*			
123	HB92-113	48° 23' 10" N	123° 31' 15" W					*			
124	HB92-114	48° 33' 45" N	123° 22' 10" W	R7 12-17							
125	HB92-115	48° 27' 20" N	123° 32' 35" W	R7 18-22							
126	HB92-116	48° 31' 10" N	123° 24' 55" W			F 003					
127	HB92-117	48° 22' 20" N	123° 31' 30" W	R8 ALL							

	A	B	C	D	E	F	G	H	I	J
1	DONE	DATE	BY	MAP SHEET	NTS #	OPEN FILE	LOCATION	NOTES	SAMPLES	Sample Use
128		14-Sep-93	HB	SIDNEY	92 B/11	1993-24	COWICHAN HEAD	HB93-118		
129		14-Sep-93	HB	SIDNEY	92 B/11	1993-24	COWICHAN HEAD	HB93-119		
130		14-Sep-93	HB	SIDNEY	92 B/11	1993-24	COWICHAN HEAD - SOUTH END	HB93-120		
131		16-Sep	HB KODI	SIDNEY	92 B/11	1993-24	CORDOVA BAY ATTEMPT	HB93-120.5		
132		17-Sep	HB KODI	SOOKE	92 B/5	1993-25	MUIR POINT	HB93-121	HB93 S1	Texture
133		21-Sep	HB JB	SIDNEY	92 B/11	1993-24	COWICHAN HEAD - SOUTH END	HB93-122		
134		23-Jul	HB	SOOKE	92 B/5	1993-25	WHIFFIN SPIT - PHOTO ONLY		NONE	

	H	K	L	M	N	O	P	Q	R	S	T
1	NOTES	LAT. North	LONG. West	PHOTOS	AIRPHOTO #	BR-STRIAE	FABRIC	MUN	B.ROCK DIP	LITH	etc.
128	HB93-118			93 R1 1-2							
129	HB93-119			R1 3-6							
130	HB93-120			R1 7-9							
131	HB93-120.5					S 172,177,175					ERRATICS
132	HB93-121			R1 13-16			~NE>SW			"	STIATED CLASTS
133	HB93-122						"			"	
134				R4-01 CS	BC82012-						

APPENDICES F: Surficial Geology Maps Of Southeastern Vancouver Island Located In Map Pockets

Blyth, H.E. and N.W. Rutter (1993a) Quaternary Geology of the Victoria map area; 1:50 000 (92B/6). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-23.

Blyth, H.E. and N.W. Rutter (1993b) Quaternary Geology of the Sidney map area; 1:50 000 (92B/11). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-24.

Blyth, H.E. and N.W. Rutter (1993c) Quaternary Geology of the Sooke map area; 1:50 000 (92B/5). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-25.

Blyth, H.E. and N.W. Rutter (1993d) Quaternary Geology of the Duncan map area; 1:50 000 (92B/13). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-27.

Blyth, H.E., N.W. Rutter and L. Sankeralli (1993) Quaternary Geology of the Shawnigan Lake map area; 1:50 000 (92B/12). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-26.

Rutter, N.W. and H.E. Blyth (1993) Quaternary Geology of the Mayne Island map area; 1:50 000 (92B/14). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-28.